

Ames

**NASA  
Reference  
Publication  
1187**

August 1987

A Perspective on 15 Years  
of Proof-of-Concept Aircraft  
Development and Flight Research  
at Ames-Moffett by the Rotorcraft  
and Powered-Lift Flight Projects  
Division, 1970-1985

David D. Few

(NASA-RP-1187) A PERSPECTIVE ON 15 YEARS OF  
PROOF-OF-CONCEPT AIRCRAFT DEVELOPMENT AND  
FLIGHT RESEARCH AT AMES-MOFFETT BY THE  
ROTORCRAFT AND POWERED-LIFT FLIGHT PROJECTS  
DIVISION, 1970-1985 (NASA) 55 p CSCI 01C H1/05

N88-19467

Unclass  
0131748

**NASA**

**NASA  
Reference  
Publication  
1187**

1987

A Perspective on 15 Years  
of Proof-of-Concept Aircraft  
Development and Flight Research  
at Ames-Moffett by the Rotorcraft  
and Powered-Lift Flight Projects  
Division, 1970-1985

David D. Few

*Ames Research Center  
Moffett Field, California*



National Aeronautics  
and Space Administration

Scientific and Technical  
Information Office

## NOMENCLATURE

$C_L$	coefficient of lift
CTOL	conventional takeoff and landing
DARPA	Defense Advanced Research Projects Agency
DTNSRDC	David Taylor Naval Systems Research and Development Center
KTAS	knots true air speed
PNdB	perceived noise level in decibels
R&T	research and technology
RCF	rotating cylinder flap
SCAS	stability and control augmentation system
STOL	short takeoff and landing
STOVL	short takeoff and vertical landing
TOFL	takeoff field length
T/W	thrust-weight
$V_C$	critical control speed
V/STOL	vertical/short takeoff and landing
V/STOLAND	vertical/short takeoff and landing avionics system
VTOL	vertical takeoff and landing

PRECEDING PAGE BLANK NOT FILMED

## SUMMARY

This paper defines a proof-of-concept (POC) aircraft and briefly describes the concept of interest for each of the six aircraft developed by the Ames-Moffett Rotorcraft and Powered-Lift Flight Projects Division from 1970 through 1985; namely, the OV-10, the C-8A Augmentor Wing, the Quiet Short-Haul Research Aircraft (QSRA), the XV-15 Tilt Rotor Research Aircraft (TRRA), the Rotor Systems Research Aircraft (RSRA)-compound, and the yet-to-fly RSRA/X-Wing Aircraft. The program/project chronology and most noteworthy features of the concepts are reviewed. The paper discusses the significance of each concept and the project that demonstrated it; it briefly looks at what concepts are on the horizon as potential POC research aircraft and states the author's emphatic belief that it is safe to say that no significant advanced concept in aviation technology has ever been accepted by civilian or military users without first completing a demonstration through flight testing.

## INTRODUCTION

Ames is the lead NASA center for rotorcraft and powered-lift research, and during the past 20 years, NASA, at Ames-Moffett, has developed or modified, tested, and to varying degrees utilized as flight research facilities about a dozen different aircraft. Of these aircraft, the Rotorcraft and Powered-Lift Flight Projects Division has been responsible for developing, conducting proof-of-concept (POC) flight tests, and performing flight research on the OV-10, the C-8A Augmentor Wing, the Quiet Short-Haul Research Aircraft (QSRA), the XV-15 Tilt-Rotor Research Aircraft (TRRA), the Rotor Systems Research Aircraft (RSRA)-compound, and the yet-to-fly RSRA/X-Wing Aircraft.

Rotary-wing and powered-lift research has covered a wide spectrum of concepts, and the technical approach is a multistep process. The process of exploring new or innovative concepts in rotorcraft and powered-lift aircraft at Ames is as follows:

1. Analytical and theoretical analyses are conducted. These include extensive use of today's computational capabilities in fluid dynamics, panel codes, and aircraft synthesis programs.

2. Small- and large-scale wind tunnel experiments are conducted to determine both low- and high-speed aerodynamic and dynamic characteristics. Scale models derived from the analytical codes are used, and the analytical results are validated.



3. Both moving and fixed-base simulations are run to predict handling characteristics, develop control laws and systems, and configure the crew station and flight controls. These simulations are also used to develop operating procedures, evaluate failures, and perform many other first-cut investigations of the characteristics of the proposed concept.

4. Finally, a unique and new (or highly modified) POC aircraft is developed and tested.

Once developed and fully tested, these typically one-of-a-kind aircraft may find other uses as a research platform, undergo further modification to concept variants, or be retired. An apparent exception to this pattern was the RSRA, which was developed initially by Langley Research Center to be a flying wind tunnel without the constraints of hard mounting and compromised flow quality found in all wind tunnels. In a sense, however, even that is a new concept for testing rotor systems.

The author gratefully acknowledges the contributions to this paper from the staff of the Rotorcraft and Powered-Lift Flight Projects Division.

#### LIFE CYCLE OF A POC RESEARCH AIRCRAFT

The general steps followed in exploring a new or innovative concept in rotorcraft and powered-lift aircraft at Ames are pictured in figure 1. One of these steps is the development of a POC research aircraft.

A POC research aircraft is loosely defined as a unique aircraft built or modified primarily to demonstrate in flight new high-risk technology and to produce technical data. The technology to be demonstrated or the concept to be proven may be an aerodynamic principle (such as the ejector-augmentor wing, upper surface blowing, or the rotating cylinder flap) or a unique configuration (such as the Tilt Rotor).

The life cycle of one of these unique aircraft is an unusual progression which is, in the writer's view, roughly divided into the following four phases.

Phase I - Aircraft development, system checkout, and airworthiness flight testing

Phase II - POC or configuration validation flight testing

Phase III - Aircraft documentation and application evaluation without major configuration changes

Phase IV - Utilization as a flight research facility or a test-bed facility for flight experiments

The technology "initial" demonstration and/or concept proof is considered complete at the conclusion of Phase II. Beyond this, a research aircraft is

utilized for producing technical data relative to the application of the technology, establishing criteria for its application, investigating areas requiring further development, and serving as a test-bed facility for research experiments with advanced systems and operating procedures. This is all done within Phases III and IV, and within the performance envelope established in Phase II.

More detailed descriptions of the four phases of a POC research aircraft follow.

### Phase I

This phase includes the detail design, fabrication, component development, assembly, and ground test of a new aircraft. It concludes with ground-taxi testing, systems checkout, and airworthiness flight testing. During this phase, the aircraft is given a limited handling-qualities assessment; systems operations are evaluated; and a limited safe-flight envelope is established from which to explore the full capabilities of the aircraft. In addition, emergency procedures are established, and simulated failures are evaluated.

### Phase II

This is the portion of the flight research program in which the full performance capabilities are explored, the flight loads and structural stability characteristics are determined, and the primary technology objectives are proven in flight. The speed, altitude, and maneuvering envelope are fully explored. Handling qualities receive an assessment in all areas of the envelope, and dynamic and static stability operating limits are established. The flight operations manual is essentially completed during this phase. Some aircraft documentation within the flight envelope is completed, although the total documentation of aircraft performance will not be completed until Phase III. At the conclusion of Phase II, private industry or the military should be in a position to determine whether the technology/concept is sufficiently mature and viable to merit starting the planning of a prototype program for an aircraft with similar performance characteristics.

Note: The ejector-augmentor-wing concept and the four-engine, upper surface blowing concepts have been proven only at low-speed, terminal-area conditions. High-speed cruise is yet to be demonstrated. Therefore, Phase II is not complete for the entire flight envelope of the concepts, although it is complete for the specific projects as they were conceived; i.e., proof of the concepts for low-speed, terminal-area operations.

### Phase III

Demonstrating aircraft applications, evaluating simulated operations, and completing the documentation for both the detailed performance and the structural loads and dynamics occur during this phase. Detailed handling-qualities assessments

take place within the established flight envelope, and the opportunity occurs for limited flight research experiments involving both hardware and procedural techniques. During this phase, aircraft modifications are minor and are not allowed to interfere with the completion of aircraft documentation, unless they are required to enhance flight safety. Design and operational data, including the development of civil and military certification criteria, are an important output of the phase. At the completion of Phase III (based on the availability of a comprehensive flight data base), private industry or the military should be able to finalize the definition of any prototype program that has been initiated.

#### Phase IV

An aircraft in this phase is treated as a calibrated, documented, thoroughly understood facility. Its characteristics are well defined and understood. Therefore it can serve as a baseline, or test-bed, facility upon which flight experiments can be conducted. Flight experiments can include procedural or operational experiments; evaluations of systems, missions, and guidance and navigational equipment; and special crew-station displays and system components (such as an all-electric actuator on a flap); as well as significant modifications to the aircraft configuration. If a significant modification is made to an aircraft (such as a new set of rotors on the Tilt Rotor, a new rotor on the RSRA, or a circulation-control wing trailing edge on the QSRA), an evaluation of its effect on potential airworthiness is made. This may require a temporary return to Phases I and II to evaluate the modification.

#### STATUS OF AMES-MOFFETT FLIGHT PROJECTS DIVISION POC AIRCRAFT

Proof-of-concept research aircraft usually have evolved as a result of extensive aerodynamic modification of an existing aircraft, or they are developed from scratch. The Augmentor Wing and QSRA are examples of the former (both being derived from the De Havilland C-8A "Buffalo"); the RSRA and XV-15 TRRA (being all new aircraft) are examples of the latter. However, even though the RSRA and TRRA were all new, both made extensive use of off-the-shelf hardware.

Each of these phases may overlap one another, and at any given time a significant modification or addition to an aircraft may warrant its movement from Phase III or IV back to Phase II or even Phase I. A research aircraft may enter service in any of Phases I through IV, or it may start at Phase I and conclude at Phase III, depending on the aircraft. The life of a research aircraft may be as brief as 3 years (as for the OV-10) or 10 years (as for the Augmentor Wing). In another Ames-Moffett division, however, the X-14 was used for 20 years before it was retired because a replacement for this VTOL type of vehicle was unavailable. It has since been replaced by an AV-8B Harrier aircraft, which will become a generic VTOL flight controls/displays and handling-qualities research aircraft.

In summary, the status of the Division's POC research aircraft as of July 1986 is:

For the XV-15, Phase II has been completed, Phase III work is being performed, and some Phase IV activity has been initiated.

The QSRA is in Phase IV.

The RSRA-compound helicopter is in Phases II and III.

The RSRA/X-Wing is in Phase I.

The OV-10 and C-8A Augmentor Wing Aircraft have been retired.

#### WHY, WHEN, AND HOW

To fully explore the benefits to aerodynamics research, it is often necessary to prove concepts and demonstrate applications during flight by using full-scale POC demonstrator aircraft. This is particularly true when a concept involves configurations radically different from those previously flown and unique aircraft dynamics which, to a large degree, cannot usually be measured in ground-based facilities. One of the values of the Ames flight research capability is its independence. The organization is able to provide independent evaluations of the many aspects of a total aircraft and/or its systems performance, and it can ensure that the technology developed is transferred to the entire aeronautical community. This mission is absolutely essential if the United States is to maintain a position of world leadership in aeronautics.

#### Directorate Level

As previously noted, Ames is NASA's lead Center for rotorcraft and powered-lift technology. Within both its Flight Operations and Research Directorate and its Aerospace Systems Directorate exists the expertise to advocate, develop, and conduct flight testing and flight research of aircraft and rotorcraft. The Center, including both the Moffett and the Dryden facilities, has developed techniques to conduct flight POC testing and research on extremely diverse vehicles and on the many systems which they contain. The individual systems, such as control systems or rotor systems, are themselves often the subject of flight research in which the aircraft becomes merely a facility or test bed.

The techniques and procedures developed to conduct this flight research are extremely rigorous in their attention to flight safety and the attainment of precise and extensive data. Relative to flight safety, extensive reviews and briefings are held before conducting envelope expansions or new procedural operations. Ames maintains a formal Airworthiness and Flight Safety Review Board and two supporting

panels, one for Moffett and one for Dryden. Also at Moffett an Airworthiness and Flight Safety Review Office serves as a catalyst and as a checkpoint for the performing organization to maintain the required discipline in this area.

#### Division Level

Within the Aerospace Systems Directorate, the Rotorcraft and Powered-Lift Flight Projects Division is the lead Division at Ames-Moffett for advocating and implementing POC (or demonstration) research aircraft projects. This is done when senior management believes that a concept or major innovation has matured to the level where a POC flight investigation or demonstration is warranted. This Division is the only organization within NASA that does POC projects for rotorcraft and powered-lift flight in the total configuration.

The Division's safety record has been good during the last 15 years, despite its using a low-cost, experimental-shop approach which maximizes the use of soft tooling and existing hardware wherever possible.

In managing these projects we have also learned that the best arrangement is a small project office with a cadre of motivated engineers with multiple disciplines, backed up by a matrix of specialists. This office, if possible, should have a resident office reporting to it at the contractor's site. A purely independent project office is not cost effective; a purely matrix organization provides little confidence that a project is being properly managed (and a project manager can hardly be held responsible for a project's success or failure). References 1 and 2 cover this subject in more detail.

#### POC AIRCRAFT DEVELOPED, TESTED, AND UTILIZED IN FLIGHT RESEARCH BY THE AMES-MOFFETT FLIGHT PROJECTS DIVISION

From 1970 through 1985, the Division has been responsible for the following six types of aircraft.

##### OV-10 Rotating-Cylinder-Flap Research Aircraft

Background and Status- The rotating-cylinder-flap concept was demonstrated as a lift-enhancing device for a short takeoff and landing (STOL) operation by installing it on the wing trailing edge of a highly modified OV-10 aircraft (figs. 2 and 3). The aircraft was modified by Rockwell Columbus under the management at Ames of James Weiberg. The power and drive train were taken from the Canadian CL-84 Tilt-Wing aircraft; the CL-84 propellers were reduced in diameter to fit the OV-10 aircraft. The cross-shafted transmissions provided engine-out capability at the lower operating speeds (i.e.,  $V_C$  was critical). The gross weight was increased from 8,500 lb to 11,500 lb and a  $C_L$  33% greater than that of the basic OV-10 was achieved. This

aircraft demonstrated the limits of powered-lift capability without using some type of VTOL reaction-control system.

The rotating cylinder flap (figures 4 and 5 illustrate the concept) was a very effective device to provide lift at low speeds. It did this in two ways: First, the rotating cylinder added energy to the boundary layer and kept the airflow attached to the airfoil, even with flap deflections of 75°. Second, the rotating cylinder flap turned the propeller thrust (vectored-thrust) to provide a powered-lift component. These features, however, did not come without a penalty. This turning of the flow, which had an adverse effect on the flow field at the tail, generated a download on the tail and caused the aircraft to pitch up. The pilot compensated for this download by applying forward stick. The slower the aircraft flew, the more forward stick was required (which is negative stability). Another way to look at this instability is to examine the change in downwash angle ( $d\epsilon$ ) with the change in angle of attack ( $d\alpha$ ). The stability equation includes a tail stability term that is expressed as  $(1 - d\epsilon/d\alpha)$ . When  $d\epsilon/d\alpha$  approaches 1 (as was the case with the OV-10 rotating cylinder aircraft), the tail stability term approaches zero. This penalty could have been minimized by programming the horizontal stabilizer position as a function of flap position. This programming would provide an increasing stabilator nose-up position as flap deflection is increased, and it will be a requirement if this concept is revisited.

The complete aircraft was tested in the 40- by 80-Foot Wind Tunnel, and was first flown in August 1971. It has since been retired.

Significance- In this first flight demonstration of the rotating-cylinder-flap concept, a flow-entrainment and boundary-layer-energizing device was used for turning the flow downward and increasing the wing lift. Unlike all or most pneumatic boundary layer control, jet flap, and similar concepts, the mechanically driven rotating cylinder required very low amounts of power; thus there was little degradation to the available takeoff horsepower. This project also successfully demonstrated the validity of modifying an existing aircraft, as a low-cost approach to a POC flight demonstration, rather than building a new vehicle.

#### Augmentor Wing Jet STOL Research Aircraft

Background and Status- The powered-lift ejector-augmentor concept (see figs. 6 and 7) was demonstrated as a powerful lift-enhancing device on a highly modified C-8A De Havilland Buffalo turboprop aircraft. The project started in 1970 as a joint NASA/Canadian Department of Industry, Trade and Commerce (DITC) effort to demonstrate the concept in the low-speed regime and in terminal-area operations. Canadian contractors (De Havilland and Rolls Royce) were responsible for the engine/nacelle package, and the Boeing Commercial Airplane Group modified the wing/fuselage/tail of the aircraft. The NASA Project Manager was David Few, and Hervey Quigley was the Technical Deputy Manager (after 1973 Hervey Quigley was Project Manager). Robert Innis was the Project Pilot. The POC project was completed on schedule and within budget, and met all project objectives.

The existing wing was shortened from 96 ft to 79 ft (aspect ratio 7.2), and gross weights as high as 48,000 lb were flown. The original turboprop engine and nacelles were replaced with Rolls Royce Spey Mk 801-SF turbo fans (fig. 8), and fixed leading-edge slats were installed. The most significant change was the installation of the new augmentor flaps, blown ailerons, and spoilers, all aft of the rear spar. The augmentor was powered by the cold flow from the front fans ducted across the wing and through the fuselage in such a way that each engine powered both flaps. Thus true engine-out capability on this two-engine jet STOL aircraft was achieved (figs. 9 and 10). The augmentor (biplane flap) employed a duct/nozzle and coanda surface for smooth flow turning, a diffuser, a choke, and a shroud (fig. 11). The hot exhaust flow was ejected through vectoring nozzles, which provided an extremely flexible aircraft, and rotated the thrust through an arc from  $6^\circ$  below horizontal down to  $104^\circ$ . The augmentor cold thrust was approximately 3,500 lb on each side, and the hot thrust was 6,700 lb on each engine. The lateral and directional control systems were extensively modified, and they included a stability-augmentation system. Climb and descent performance data for speed vs the flightpath angle ( $\gamma$ ) are shown in figure 12.

The aircraft was first flown on May 1, 1972, and its flight research continued at Ames through 1976, during which time a powered elevator was installed. It was transferred in 1976 to Canada, where research was conducted for several years. It is now retired and is destined to be installed in a Canadian museum.

Significance- The "Aug Wing" successfully demonstrated the augmentor concept by achieving thrust augmentation ratios of about 1.20. It was the world's first jet STOL transport demonstrator. Additionally, it demonstrated and enabled evaluating the advantage of using direct-lift thrust control and spoilers in precise steep flightpath control. The aircraft demonstrated significant gains in  $C_L$  (up to  $C_{L\text{ max}}$  of 5.5 and an operating  $C_L$  of 3.9). Nominal approach speeds of 60 knots were routine, and speeds as low as 50 knots were demonstrated when it flew on the back side of the power curve, where an increase in power actually reduced speed. Takeoff and landing distances of less than 1,000 ft over a 50-ft-high obstacle were routinely demonstrated, and ground rolls at as low as 350 ft were achieved. The concept continues to be a favored approach by some members of private industry for an operational jet STOL application. Its high-speed cruise performance is yet to be demonstrated in flight.

#### Tilt-Rotor Research Aircraft

Background and Status- The convertiplane (i.e., an aircraft that can fly as a helicopter and can convert the rotors to the propeller position, as in a turboprop) was first flight tested successfully in the 1950s with the XV-3 and was used into the 1960s. This aircraft (fig. 13) demonstrated the feasibility of the idea, but it was severely underpowered and limited in speed and payload. This test also uncovered a potentially catastrophic, whirl-mode instability problem.

By the late 1960s, NASA, Army, and private industry engineers believed they had solved the instability problems, and in 1972 the joint NASA Ames/Army XV-15 program

was begun (figs. 14 and 15). This program was to develop two tilt-prop rotor research aircraft capable of demonstrating, in flight, the viability of the concept for entry into the military and civil transportation systems.

Bell Helicopter won a competition to do the detail design and fabrication of the vehicle. The first Project Manager was David Few; the Deputies were Dean Borgman and Michael Carness. Subsequent Project Managers were Lt. Col. James Brown, then David Few again (after Lt. Col. Brown retired) until John Magee was selected. John became the Project Manager during the latter part of Phase II, which was completed in 1981. Lt. Col. Clifford McKeithan was appointed Deputy during this period. James Lane was the Resident Manager at Bell, and Daniel Dugan and Ronald Gerdes were Ames Project Pilots. The flight research for the aircraft is currently managed by Laurel "Shorty" Schroers.

The goal of the project was to demonstrate an aircraft free of structural aeroelastic instabilities and also to demonstrate one that was able to achieve a 300-knot airspeed with enough maneuvering envelope for the military to evaluate the aircraft for both potential and existing mission suitability.

The aircraft that was developed is a minimum-cost vehicle using as many off-the-shelf components as is practical (fig. 16). In this 13,000-lb gross weight VTOL aircraft (15,000 lb for short takeoff), every critical system is either redundant or overdesigned for safety of flight considerations. The aircraft, in addition, is fitted with ejection seats. The prop-rotors are installed in nacelles at the wing-tips, and they can rotate 95° (from horizontal up to 5° aft of vertical). The transmissions are Bell development/prototypes; the landing gear is from the Canadian CL-84; and the engines are T-53s of the Huey era. The wing, fuselage, and empennage are new, as are the prop-rotors themselves. The aircraft, which first flew on May 3, 1977 (fig. 17), enjoys good flying qualities; it is today a valuable research facility at Ames for conducting flight experiments on this exciting and useful concept. The other of the two aircraft is operated for NASA and the Army at Bell's Flight Test Facility in Texas. Figures 18-23 illustrate the concept and its unique components.

The Tilt-Rotor aircraft has three viable flight modes. These are the helicopter mode with pylon angles from 95° to 75°, the tilt-rotor mode with pylon angles of 75° to 0°, and the airplane mode. Of all the VTOL concepts evaluated to date, only the tilt-rotor concept provides a viable and useful partially converted mode. The combination of helicopter rotor control moments and the airplane control moments provide more than enough control power to satisfy the requirements for maneuvering, trim, and gust upset. A jet-lift aircraft, however, such as the Ames AV-8B Harrier, has a very limited maneuvering capability in the partially converted mode because aerodynamic moments (rolling moment caused by sideslip) can easily and quite suddenly overpower the control power achieved by the bleed-air reaction controls at the wingtips and tail. Typical performance characteristics are shown in figures 24-26, and hover noise level is shown in figure 27. Although very acceptable in hover (about 90 dB at 500 ft), the noise level in airplane mode is so low that it would fade into the background in most areas where the aircraft would operate (70 dB at 200 knots and 1000-ft distance).



Significance- The proof of the tilt-rotor (prop-rotor) concept was very successfully demonstrated by the NASA Ames/Army program, and all the project goals and objectives were achieved. In addition, even though two entirely new aircraft had to be developed during a highly inflationary period, the project was accomplished for a very reasonable cost (10% over the original budget of \$40 million). Of special significance to NASA is that the project has been accepted by the military as a direct result of our efforts. It will be applied to an operational aircraft development program: approximately 1000 V-22 Tilt-Rotor Ospreys have been ordered for initial use by the Marines, with subsequent production planned for the Army, Air Force, and Navy. In addition to proving the concept in flight and enabling the creation of a tilt-rotor flight data base, the aircraft enabled hands-on evaluations by over 100 military and industry pilots. These evaluations included military assessments such as on-board carrier operations, air-to-air combat simulations, nap-of-the-earth (NOE) conditions, air-refueling simulations, and detectability investigations. As noted earlier, the XV-15 is now in Phases III and IV. As a Phase IV facility, it is being used to develop advanced rotorcraft control law theory; evaluate advanced technology rotor blades, after an initial Phase II envelope expansion; and verify the design approaches being implemented on the V-22 Osprey program.

For the first time, the United States will have an aircraft (in the V-22) that can take off and land vertically, hover efficiently, and cruise at speeds of about 275 KTAS. In addition to high speed, the tilt-rotor concept offers advantages with respect to fuel economy and reduced noise and vibration; hence, many variant configurations are anticipated. Ames researchers are currently working toward a 400+-knot tilt rotor as an achievable second-generation machine for this exciting concept. Ames former Directors, C. A. Syvertson and H. Mark, have both stated that the Tilt-Rotor Project was the most significant accomplishment in aeronautics at Ames in the last 20 years, and they said that the aircraft was the "hit" of the Paris Airshow in 1981.

#### Quiet Short-Haul Research Aircraft

Background and Status- This POC powered-lift aircraft (figs. 28 and 29) was developed to demonstrate, in the low-speed regime, the viability of the upper surface blowing (USB) concept as a very powerful lift enhancer for STOL aircraft and to do so for a reasonable cost. It utilizes a De Havilland C-8A Buffalo aircraft, as did the Aug Wing, but it has an entirely new wing which was built and installed by the Boeing Commercial Airplane Group. Even though this wing is designed to emulate a Mach 0.74 supercritical airfoil, the aircraft itself is limited to low-speed, terminal-area, research flying.

Four prototype ALF-502 (YF102) fan-jet engines are installed over the wing. The QSRA wing trailing edge consists of simple USB flaps installed behind the engines, double-slotted flaps outboard of them, and blown ailerons (fig. 30). The USB principle uses the engine exhaust jet which flows over the top of the wing and the coanda effect to deflect the engine thrust down over the deflected flaps, thereby converting thrust to lift. At the same time, the exhaust induces a pumping

action over the upper surface of the wing, which increases the wing's circulation lift (as shown in fig. 31). This propulsive-lift concept enables the wing and propulsion system to generate three times the lift of a conventional wing at low airspeeds. The "Q" has achieved very high  $C_L$  (operational landing approach  $C_L$  of 5.5, and a maximum  $C_L$  of 11) and is routinely flown at approach speeds as low as 60 knots (significant for an 80-lb/ft<sup>2</sup> wing loading). The aircraft also incorporates an extensive advanced SCAS, programmable pilot-panel and head-up displays, and many redundant aircraft systems for safety of flight. The aircraft flies easily on three engines and can be flown on two.

The Project was advocated and managed initially by Wallace Deckert. After the Boeing contract was awarded, and throughout Phases I and II, the Manager was John Cochran; his Deputies were Darrell Wilcox and Fred Baker. Phases III and IV have been managed by Dennis Riddle.

The aircraft first flew on July 6, 1978, and, with over 550 flight hours completed, is available today as a powered-lift flight-research facility. Current research includes the generation of a data base for landing-field-length criteria for civil and military operations. In-flight measurements have been made of the downwash flow field at the T-tail and at the location of a conventional fuselage-mounted tail. Tests are planned to measure the upwash flow field at a location consistent with a canard control surface. Additional modifications, with DOD and industry support, may result in a jump strut demonstration experiment and a USB/circulation-control, trailing-edge, flight-research program (fig. 32).

Significance- The QSRA has proved the viability of the USB concept for the four-engine configuration in the low-speed regime. In addition, the project was completed on schedule and below the original budget. There are plans existing to answer the high-speed drag question in the future, pending availability of funding.

The application of USB to military needs, both Navy and Air Force, was demonstrated. During aircraft carrier trials aboard the Kitty Hawk, with 30-knot winds over the deck, takeoff distances of less than 300 ft and landing distances of less than 200 ft were achieved. For Air Force applications on partially bombed runways, a takeoff of less than 700 ft and a landing of less than 800 ft (without thrust reversers and with zero wind conditions) were demonstrated. All of this was accomplished at 60-70 knots (not 130 knots)--truly an important added safety factor for passengers and crew (figs. 33 and 34).

The utilization of this propulsive-lift technique, when fully demonstrated across the entire speed range, will demand that aircraft designers as well as the nation's universities rethink their design approach to all transport aircraft. Why? Because even with the conventional thrust-to-weight ratios of 0.3 used on CTOL aircraft, such as the 727 and DC-9, takeoff field lengths could be reduced from nearly 5,000 ft to 3,000 ft. Landing distances would be similarly reduced because of the lower touchdown speeds. The real payoff, however, may be the added flexibility of a significantly increased payload: up to 25% more. That spells increased productivity (fig. 35).

The Q achieved a real milestone in noise abatement and easily met the requirements of Federal Aviation Regulation 36. It recently flew demonstrations at the noise-sensitive Monterey (California) airport and was undetected by either local residents or the airport's monitoring microphones. It was also flown to the Paris Airshow across Canada and the North Atlantic, with an all-Ames team, where it was a popular addition to the flight demonstrations at the show. It is a spectacular performer which must be seen to be fully appreciated. It is a concept championed by a significant and growing number in the aeronautical community, including Japan's National Aeronautical Laboratory. Like the Augmentor Wing concept, the four-engine USB concept requires a high-speed demonstration for completion of envelope expansion; but time is running short if this country's leadership in the concept is to continue.

### Rotor Systems Research Aircraft

Background and Status- Initiated in the early 1970s, the RSRA, a multipurpose flying wind tunnel, was designed specifically for flight testing of current and advanced rotor systems. The RSRA and the RSRA-compound were jointly managed by NASA and the Army at Langley Research Center. The aircraft were built by Sikorsky Aircraft (figs. 36 and 37). The Phase I Project Manager was Robert Huston, who was succeeded by Agusta "Gus" Guastaferro. The development program was curtailed in 1977 because of funding constraints. In 1978 it was transferred to Ames and was managed by Gregory Condon. (It came to Ames along with other Langley helicopters, as mentioned previously.) The current manager of the RSRA-compound is Edward Seto. The helicopter aircraft is at Sikorsky undergoing modification for the X-wing Project.

The objective of the concept was to provide a highly sophisticated and much-needed tool for the continued development and understanding of rotary-wing technology. It was envisioned that the RSRA would reduce much of the costly, time-consuming trial-and-error experimentation that has forced rotorcraft development to proceed at such a slow evolutionary pace. The aircraft has unique features that provide the capability of measuring characteristics of rotors and rotorcraft that heretofore have been unmeasurable either in flight or in ground test facilities.

In the helicopter configuration, the RSRA has a design gross weight of 18,400 lb. It is powered by a Sikorsky S-61 rotor and drive system, which consists of two T-58-GE-5 turboshaft engines driving the S-61 main transmission, the main rotor (62-ft diam), tail takeoff drive shaft, intermediate gear box, tail gear box, and the tail rotor (11-ft diam). The horizontal stabilizer is a T-tail with a 13.25-ft span and an area of 35.4 ft<sup>2</sup>.

In the compound configuration, the RSRA has a design gross weight of 26,200 lb. Wing and auxiliary thrust jet engines have been added to the helicopter, and the tail has been modified with the addition of a 22.5-ft span stabilator and a rudder and associated controls. The wing has a 45-ft span and includes both aileron and flap surfaces. The wing incidence is variable in flight from -9° to +15°. The two

auxiliary jet engines are TF-34-GE-400A high-bypass-ratio turbofans with maximum rated static thrust of 9,275 lb each.

Designed to fly as a pure helicopter, compound helicopter, or fixed-wing aircraft, the RSRA can be used to develop and test a wide variety of rotor systems and integrated propulsion systems. In addition, it can serve as a standardized base for comparing them. It provides highly accurate test and measurement capabilities that extend beyond those of ground-based wind tunnels or other existing aircraft. With the RSRA, rotor systems can be tested in high-gravity, NOE maneuvers; at speeds as low as hover and as high as 275 knots; and over a wide altitude envelope. This is not possible in a wind tunnel; nor is the high-speed, out-of-the-envelope testing possible on a conventional helicopter.

The RSRA is also capable of separating in-flight rotor characteristics from aircraft characteristics, another capability not presently available. The unique load cell system allows for direct measurement of each main rotor thrust, wing lift, and tail rotor thrust (fig. 38). Because of its fixed-wing and auxiliary jet engines, the RSRA is capable of testing rotor systems that might otherwise be too small to support the aircraft or systems with unproven control characteristics. It also provides for driving the main rotor to speeds in excess of what could be achieved on a conventional helicopter and throughout an infinite variety of loading conditions.

To provide an extra margin of safety for the test crew, the RSRA is equipped with one of the first crew escape systems (Blade Severance and Ejection seats) ever developed for a rotorcraft (fig. 39). Other features include a fly-by-wire control system, and eventually will include an electronic flight-control system with an on-board digital computer to control the vehicle during research missions and to carry out automatic preprogrammed maneuvers. (Figs. 40 and 41 illustrate the envelope and selected experiments.)

Significance- Although the RSRA was designed and built with all the aforementioned unique capabilities, its development has only recently achieved a near-operational status, and its full capabilities have not yet been demonstrated. The aircraft was first flown in 1976, and one RSRA is still flying with its original five-bladed (S-61) rotor system. The design for adapting a modern four-bladed rotor is complete, but is on hold pending funding availability to implement this change. Almost 10 years were needed to complete Phase I because of various hardware, manpower, and money constraint problems. Developmental flying has been carried out in all aircraft configurations. Also, several small, but worthwhile, research experiments (such as areas of performance with vertical drag and hub drag) have been accomplished and reported. Utilizing the second aircraft, the upcoming RSRA/X-Wing promises to open up an entirely new concept.

Presently, the compound RSRA is in Phase II of its life cycle, and a few Phase III research experiments in both the compound and helicopter configurations will continue. A comprehensive rotor measurement system calibration is planned for the latter part of 1986. This is an important element in the conduct of RSRA flight

experiments. Eventually it is hoped the RSRA will be a viable candidate for a state-of-the-art, high-speed rotor.

### RSRA/X-Wing Flight Experiment

Background and Status- The RSRA/X-Wing (figs. 42, 43) is now being used as a flying wind tunnel to test the X-Wing concept for rotary-wing flight, fixed-wing flight, and conversion and reconversion. The X-Wing concept (fig. 44) promises the first convertiplane vehicle that will provide rotary-wing, low-disc-loading VTOL capability combined with fixed-wing, high-subsonic, turbojet performance. The concept employs a symmetrical airfoil in a four-blade X-arrangement. Lift and control moments are provided by circulation control, introduced through leading- and trailing-edge slots in the airfoil, which gives the desired over-wing aerodynamic flow, or shape, as seen by the free airstream (fig. 45). The flow is varied about the azimuth (fig. 46) and by a valving arrangement that controls the amount of air feeding into each blade slot (fig. 47). The concept has been tested in the Ames 40- by 80-Foot Wind Tunnel at the 25-ft-diam, 3,200-lb-lift size. The 25-ft rotor was built by Lockheed, and it eventually produced even greater lift in hover at Lockheed's Rye Canyon, California, facility.

By November 1982 sufficient engineering research and development had been conducted by DARPA, NASA, Navy, and industry to launch a bold, somewhat high-risk, joint project to develop and flight test a large X-Wing rotor system. To avoid the very costly (well in excess of \$1 billion) development of a complete aircraft, it was decided to conduct the investigation with one of Ames' two Sikorsky-built RSRA aircraft and to take advantage of the fixed-wing and load-measuring capabilities of the vehicle's design (see fig. 38). The Project has been managed since its inception by James Lane and his deputies, John Burks and James Biggers (DTNSRDC). John Burks has recently been succeeded by Paul Loschke.

The rotor is 57.7 ft in diameter. It has a fully configured air compressor and air-control-distribution system (referred to as the pneumodynamic system), and a Quad Redundant Flight Control or Vehicle Management System. In July 1986 the vehicle was undergoing modification at Sikorsky to accept the X-Wing Rotor System and Vehicle Management System. Delivery to Ames-Dryden took place in September 1986 and first flight in the fixed-wing configuration is scheduled to take place in 1987. Rotary-wing flight will follow and then the all-important conversion and reconversion from rotary-wing flight to fixed-wing flight, and back to rotary-wing flight will occur. (It is predicted this will occur most easily in the 180- to 210-knot range.)

Significance- The X-Wing concept promises the first low-disc-loading VTOL vehicle with high subsonic turbojet cruise capability that does not require auxiliary propulsion or lifting devices (fig. 48). The X-Wing provides the lift in all modes of flight; in an operational production configuration, the convertible engine will divide its power between the rotor and exhaust thrust as required.

## WHAT NEXT

At the moment, the focal points of Division POC and flight research activity involves the following five areas:

1. Supersonic STOVL concepts analyses and studies, initial ground-based testing and concept selection for a POC aircraft and its required major ground-based program.
2. Second-generation, high-speed, tilt-rotor definition, currently being worked by both the Rotorcraft and Powered-Lift Flight Projects Division and by the Full-Scale Aerodynamics Research Division (both in the Aerospace Systems Directorate). A folding Tilt-Rotor and other configurations will also be considered along with the conventional approach.
3. Second-generation RSRA/X-Wing definition, currently being worked by the Rotorcraft and Powered-Lift Flight Projects Division, the Fluid Dynamics Division (Aerophysics Directorate), and the Navy DTNSRDC.
4. Advanced rotor systems development for reducing noise and vibration in conventional rotorcraft and for developing a true high-speed rotor for a 200+-knot helicopter.
5. Collaborative work with the Air Force on VTOL and super-STOL transports.

Ames, dedicated to being the Center of excellence in rotorcraft and powered-lift technology, with the OV-10, the Aug Wing, the Q, and the Tilt Rotor, was an exciting beehive of activity during the 1970s. The 1980s have provided the challenge of completing compound RSRA development and the extremely challenging RSRA/X-Wing Rotor System Flight Project.

The 1990s promise the best chance yet to see a Supersonic STOVL aircraft available for use by the Air Force and Navy that will free them from dependence on expensive large carriers and vulnerable fixed runways. When the V-22 Tilt Rotor Osprey and its civil descendents begin to be utilized, the applications will demand a second-generation 400+-knot tilt rotor. This will require a new approach to tilt-rotor structural dynamic stability and drag reduction that will present many challenges to Ames in this coming decade. Development of an operational X-Wing will require a significant amount of supporting research and technology to bring it to fruition in the 1990s. Ames' association with the Air Force to develop a VSTOL or super-STOL tactical jet transport demonstrator aircraft will advance fixed-wing/powered-lift aircraft development to a new high. The time between now and the year 2000 should be extremely stimulating for our engineers and scientists.

## CLOSING REMARKS

From 1970 to 1985, flight research activities at Ames-Moffett have contributed information instrumental to the development of America's rotorcraft and powered-lift technology. However, it is extremely important to remember that the most successful of those activities were preceded by a varying mix of analytical studies, small- and large-scale wind tunnel investigations, and piloted real-time simulations.

Recently we have seen developments in computational fluid mechanics, improved insight into structural dynamics and aeroelastics, jets in cross-flow predictive capability, and modeling techniques obtained with today's vastly enhanced computational power. Still, these have not provided validated solutions (such as Navier-Stokes, Euler, and Panel codes) throughout the broad and complex range of interaction and interference flow conditions that are experienced by rotorcraft and powered-lift aircraft. This is true both for in- and out-of-ground effects. Therefore, in the near term, experimental evaluations are still required for validating the developing analytical methodology and for documenting the VTOL, STOL, and high-speed cruise characteristics of interest.

Wind tunnel testing of small-scale models remains, at this point, an important tool for developing new concepts and for providing the necessary baseline data. Scaling issues (both aerodynamic and structural dynamic) will continue to necessitate the use of large-scale wind tunnel facilities and models. However, limitations in their use are recognized: the constraints of the wind tunnel walls on the airflows, the maximum airspeed capability of the wind tunnel, or the influence of the test model retention (mounting) on the structural dynamics or on interference flows. (Recent examples include the OV-10 Rotating-Cylinder-Flap Research Aircraft and the XV-15 Tilt-Rotor Research Aircraft. Both demonstrate different flow characteristics at the tail for in-flight results as compared to wind tunnel results.) In addition, dynamic flight conditions cannot be completely evaluated in a wind tunnel.

Piloted simulations have been effectively used to develop and evaluate aircraft control laws, crew-station configurations (human/machine interface), and crew-station avionics and displays. They are also used to evaluate failures and develop pilot emergency operating procedures. The simulations require the use of a computer code which provides, in real time, calculation of aircraft flight dynamics and control-system characteristics. The validity of the mathematical model used for the simulation remains a major concern that can be fully satisfied only by comparing simulator data with flight test results. Additional factors affecting results of piloted simulations include the quality of the visual display and the motion limitations of the moving base cabin.

It is therefore clear, to this writer at least, that with today's methodology, the final POC can be achieved only through flight demonstration and flight research investigation. Furthermore, to achieve the application of new rotorcraft and powered-lift technology, actual flight demonstrations of the concept and its potential are required. It is safe to say that no significant advanced concept in aviation technology has ever been accepted by civilian or military users without first

completing a demonstration through actual flight testing. As an example of this, the Navy/Marine/Air Force order for a production program for more than 1000 V-22 Tilt-Rotor Ospreys is seen to be the direct result of the Army/NASA Ames-Moffett XV-15 Tilt-Rotor Project, its flight test program, and many operational demonstrations.

Ames Research Center  
National Aeronautics and Space Administration  
Moffett Field, CA 94035  
November 19, 1986



## REFERENCES

1. Few, David D.: A Guide to Management of OAST Experimental Programs at Ames Research Center ("Experimental Shop Concept"). NASA TM X-62,427, April 1975.
2. Diehl, James J.: Application of a Cost/Performance Measurement System on a Research Aircraft Project. NASA TM 78498.

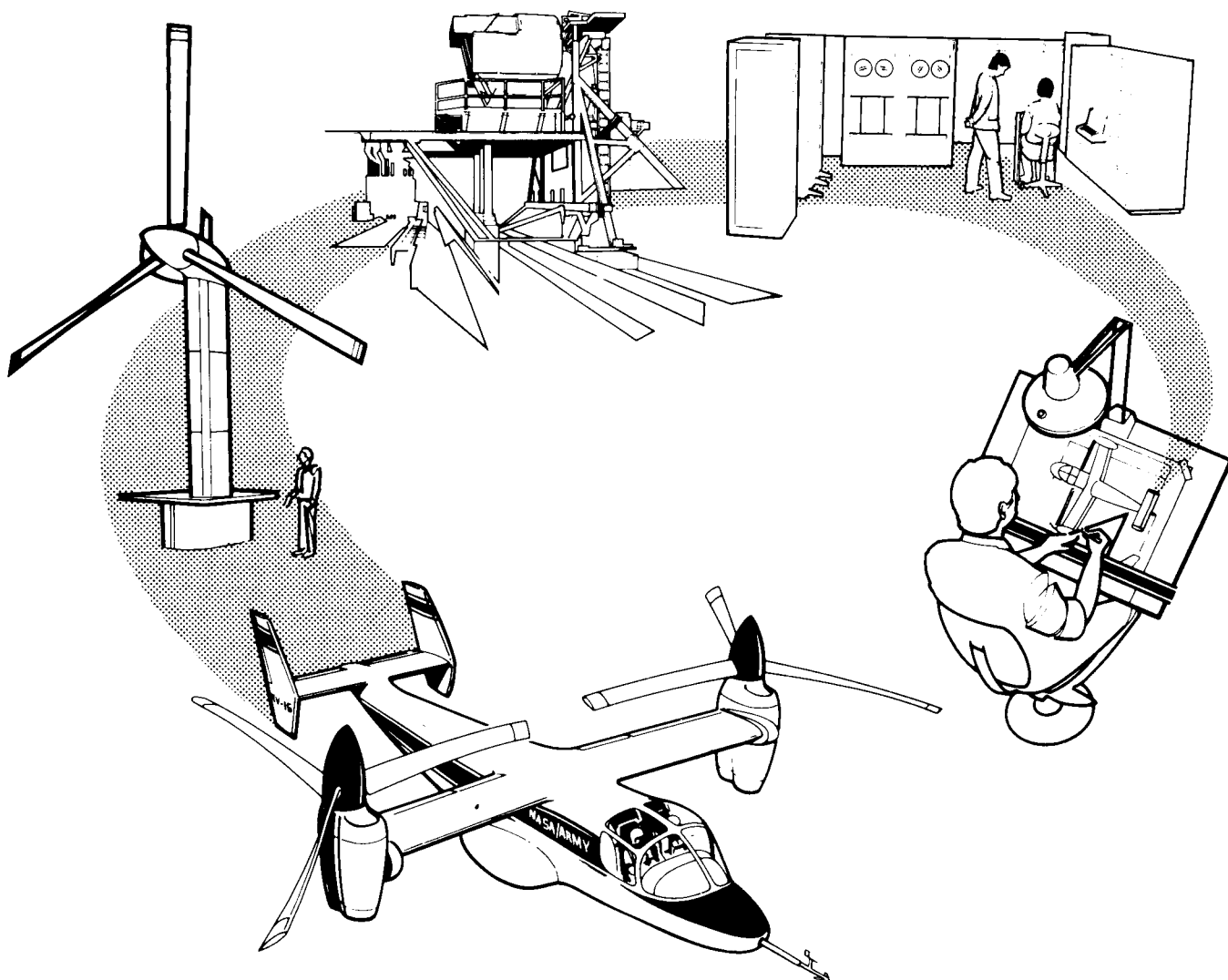


Figure 1.- Concept evolution at Ames.

ORIGINAL PAGE IS  
OF POOR QUALITY

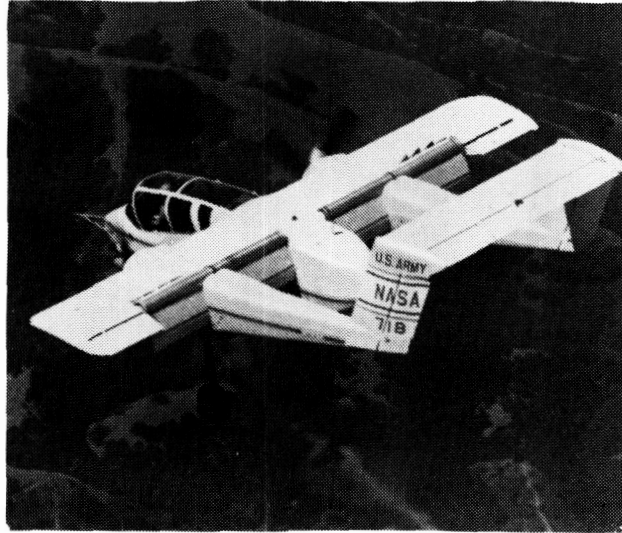


Figure 2.- OV-10 Rotating-Cylinder-Flap Research Aircraft.

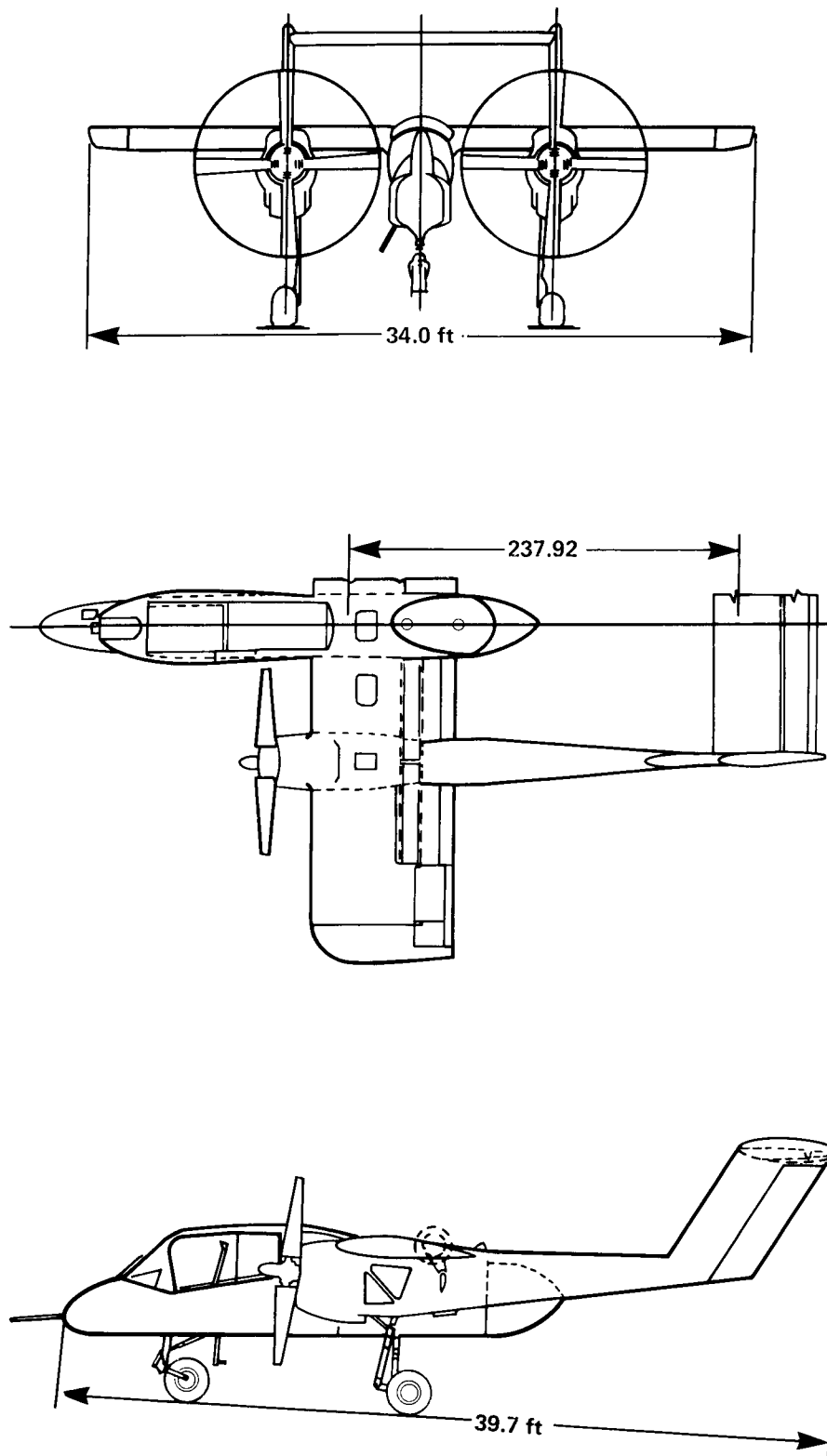


Figure 3.- Three-view diagram of YOY-10A RCF/STOL Research Aircraft.



Figure 4.- Rotating-cylinder-flap streamlines.

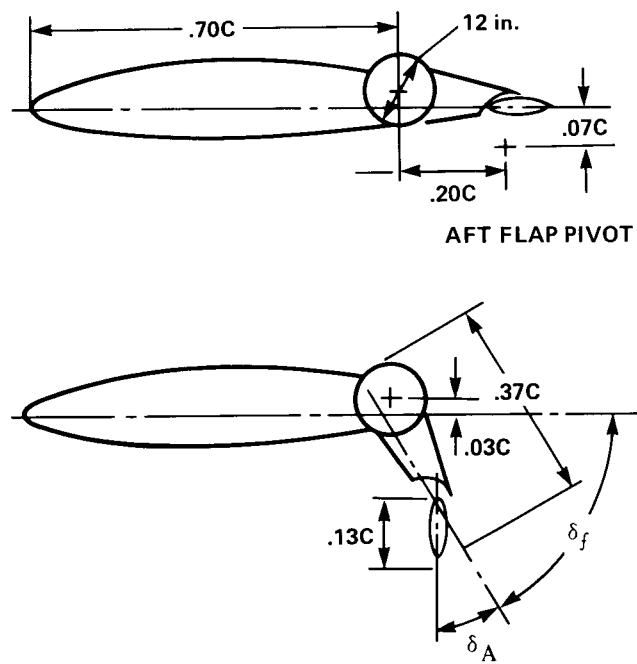


Figure 5.- Rotating-cylinder-flap geometry.

ORIGINAL PAGE IS  
OF POOR QUALITY



Figure 6.- First flight of the Augmentor Wing Jet STOL Research Aircraft, May 1, 1972, Boeing Field, Seattle.

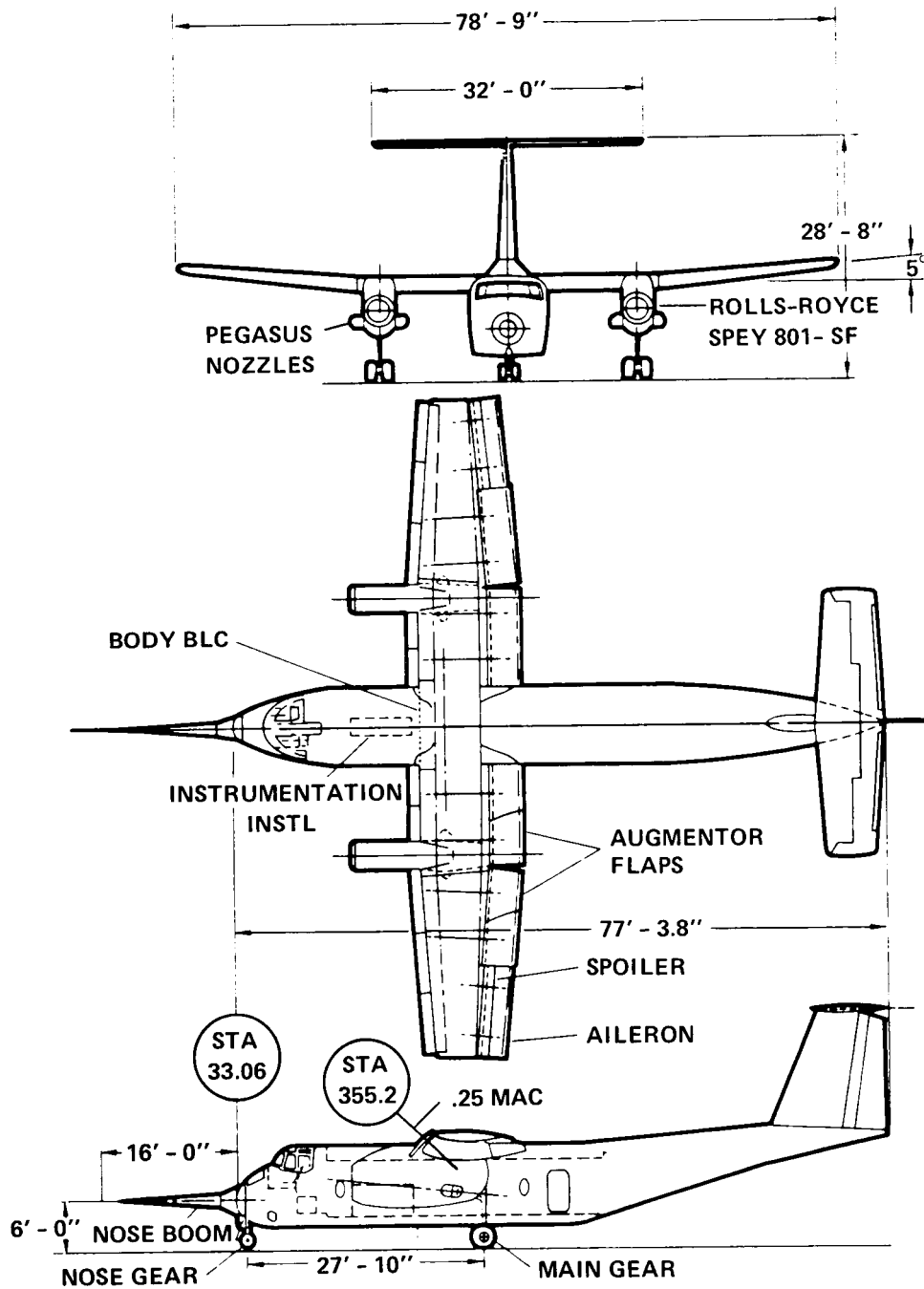


Figure 7.- Three-view diagram of Modified C-8A, Augmentor Wing Jet STOL Research Aircraft.

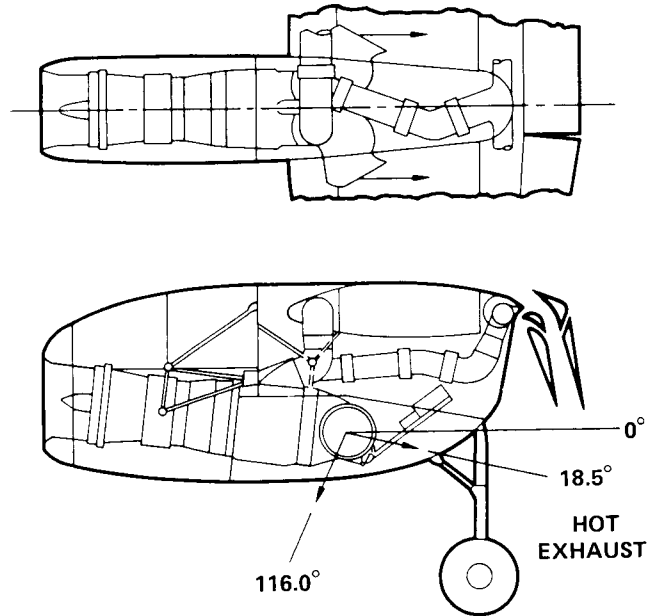


Figure 8.- Augmentor Wing propulsion nacelle.

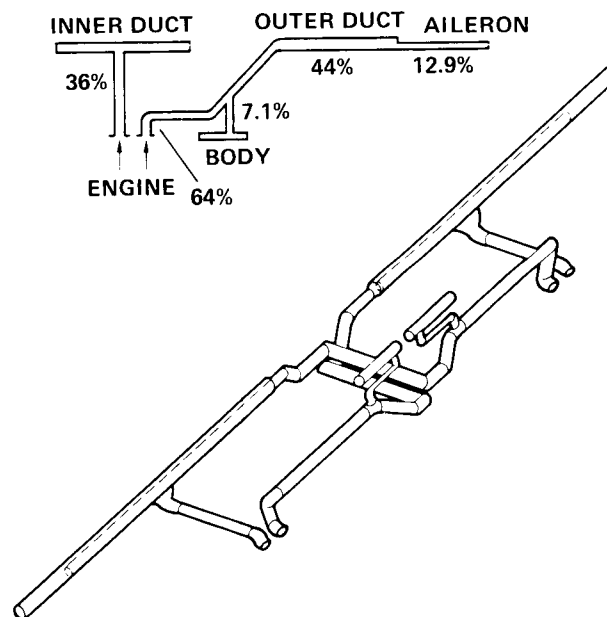


Figure 9.- Augmentor Wing duct configuration and percentage of cold-flow distribution.



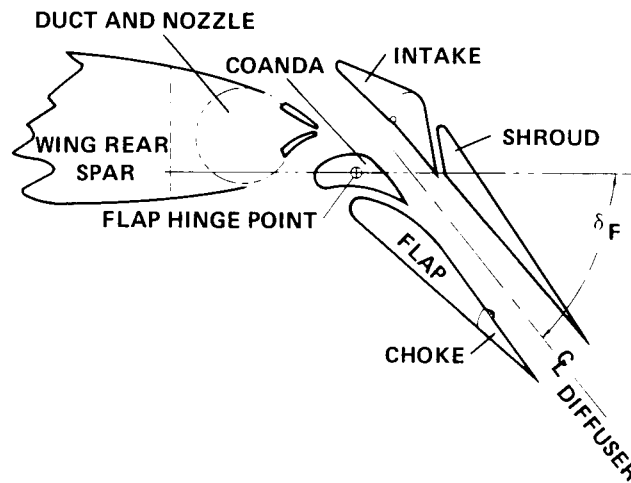


Figure 10.- Augmentor Wing duct assembly.

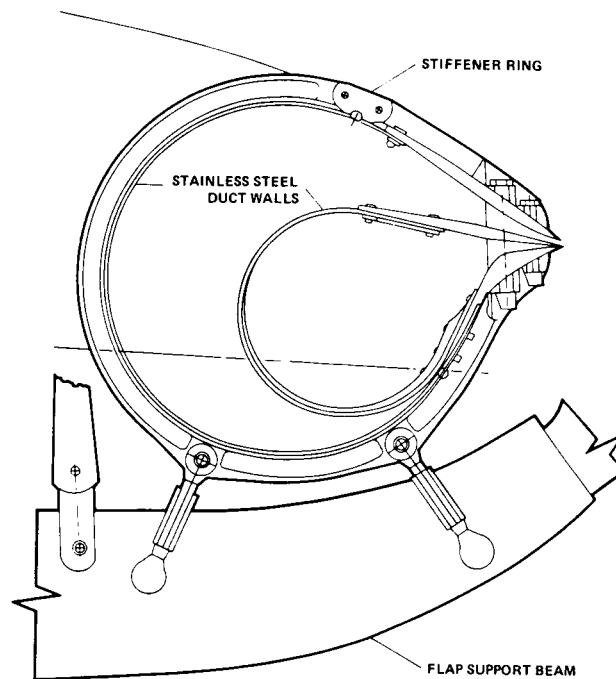


Figure 11.- Augmentor Wing flap arrangement.

ORIGINAL PAGE 13  
OF POOR QUALITY

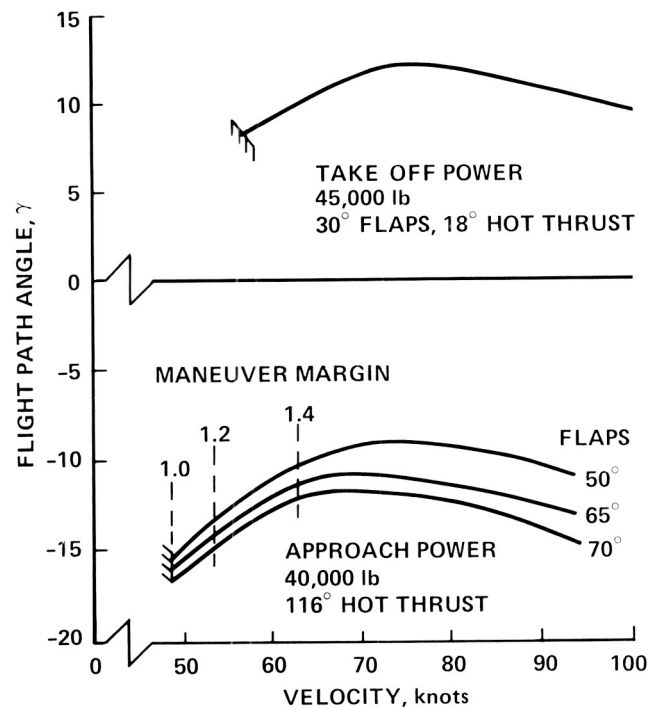
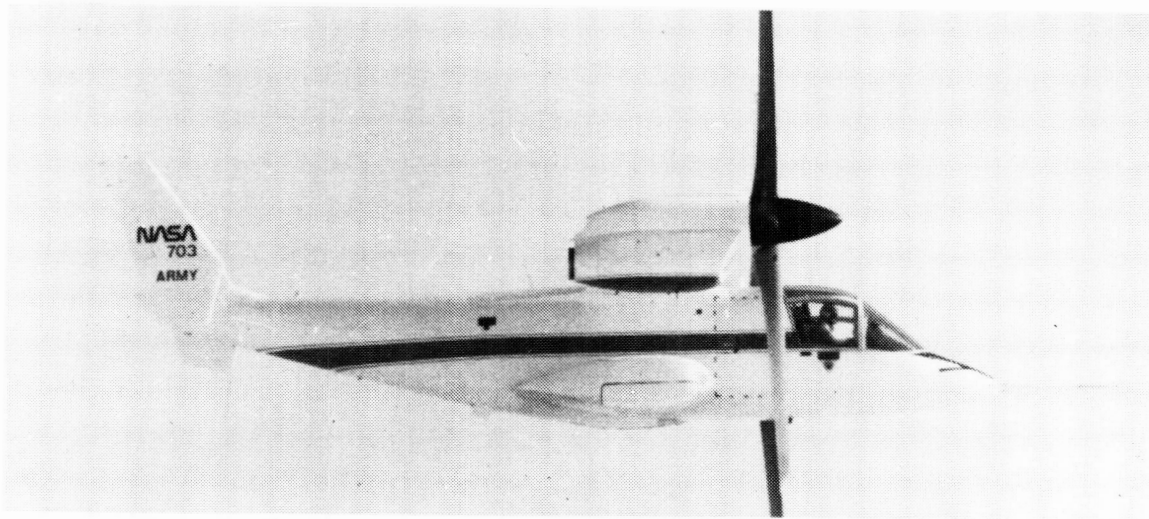


Figure 12.- Augmentor Wing Jet STOL climb and descent performance data for speed vs the flightpath angle,  $\gamma$ .

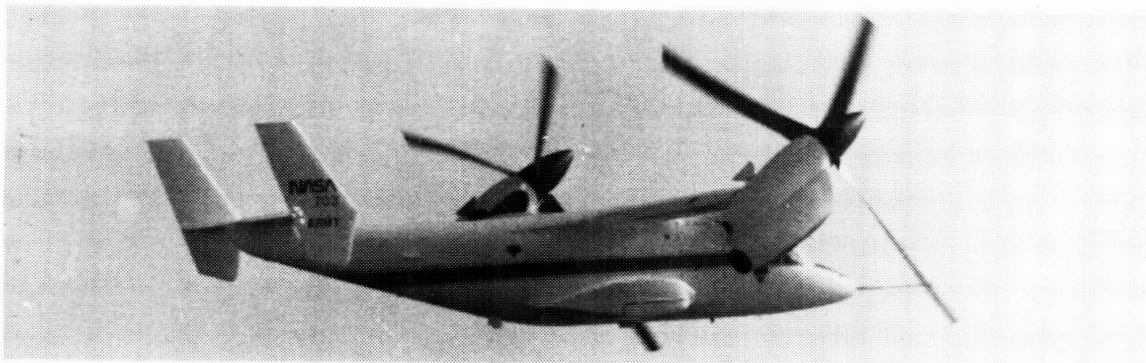


Figure 13.- XV-3 Tilt-Rotor Research Aircraft, circa 1960.

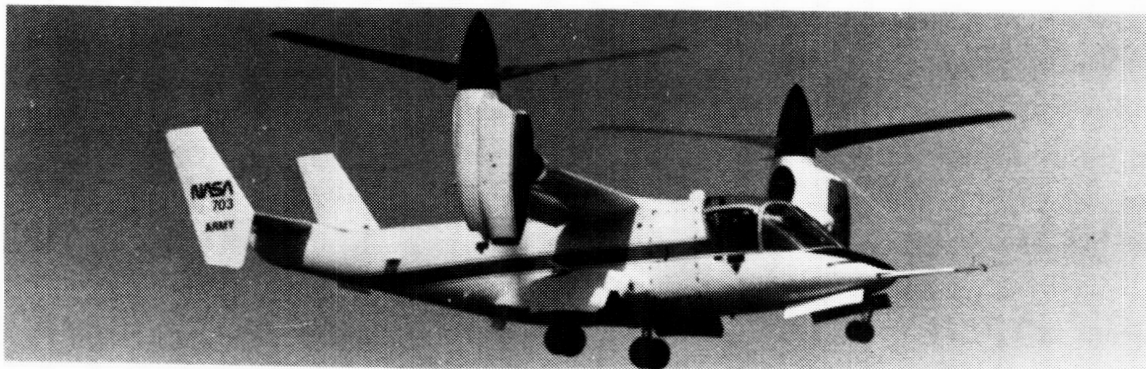
ORIGINAL PAGE IS  
OF POOR QUALITY



**AIRPLANE**



**TRANSITION**



**HELICOPTER**

Figure 14.- XV-15 Tilt-Rotor Research Aircraft in its three flight modes.

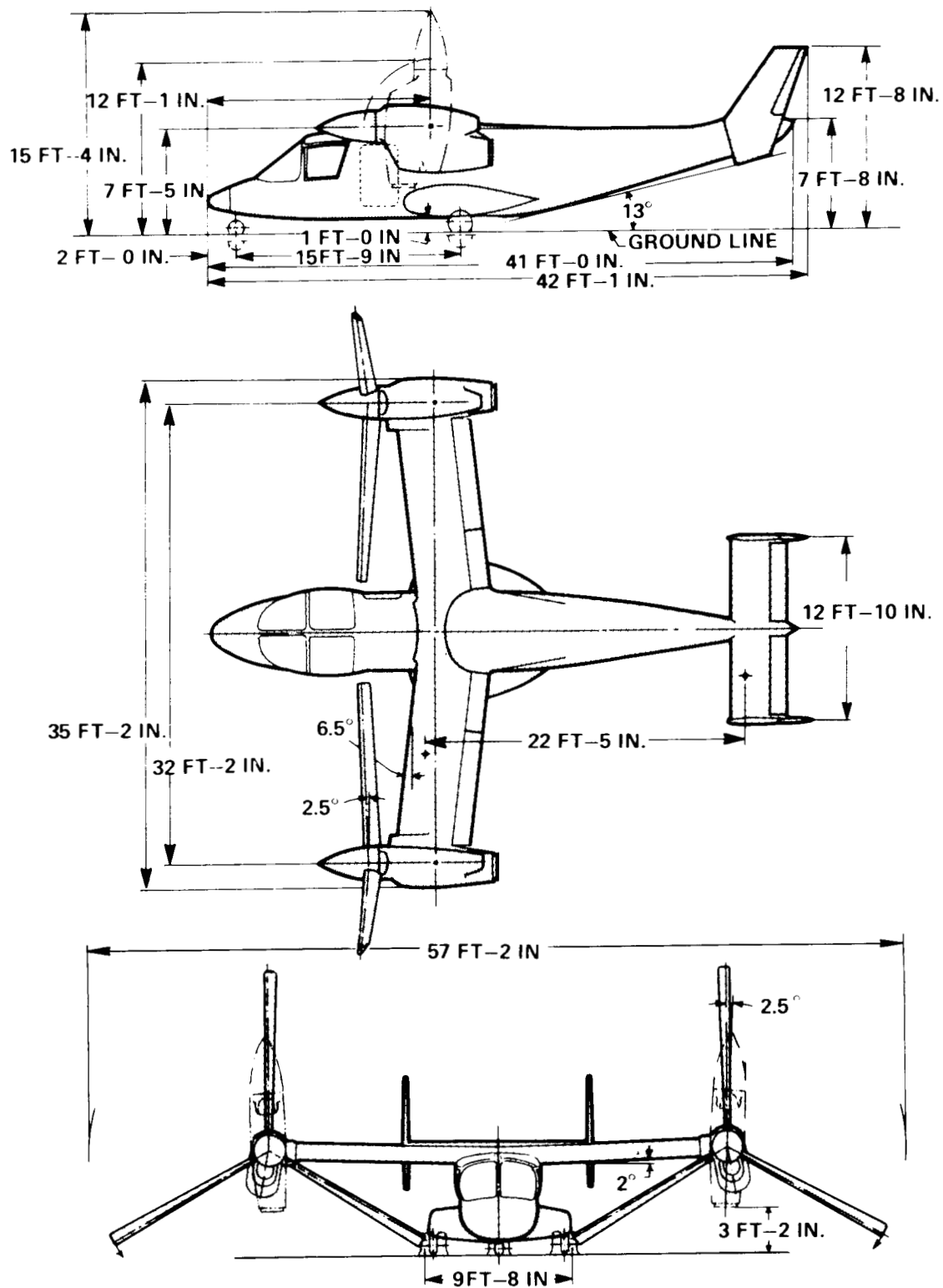


Figure 15.- Three-view diagram of Army/NASA XV-15 Tilt-Rotor Research Aircraft.

ORIGINAL PAGE IS  
OF POOR QUALITY

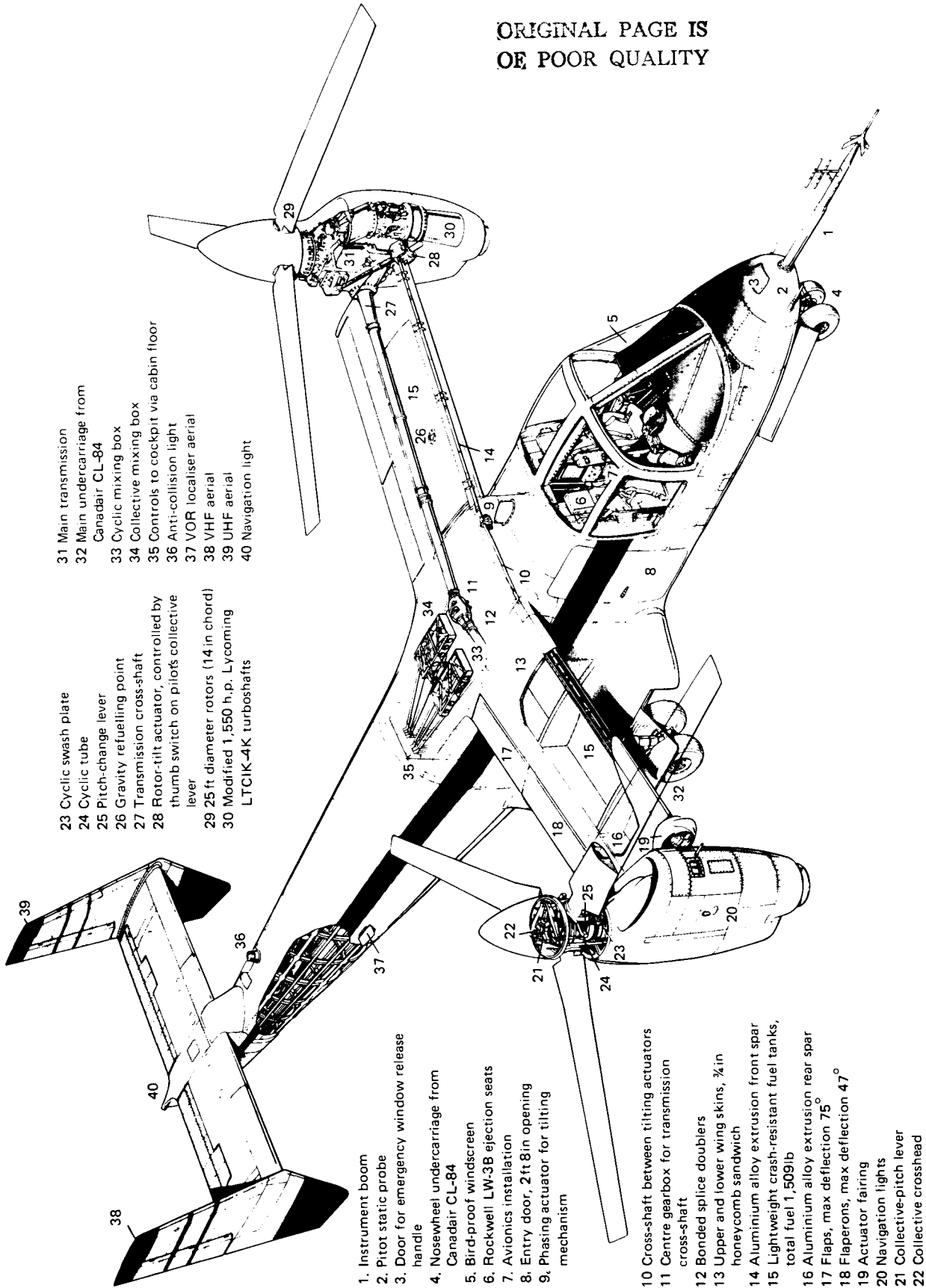


Figure 16.- XV-15 Tilt-Rotor Research Aircraft general layout and major components.

ORIGINAL PAGE IS  
OF POOR QUALITY

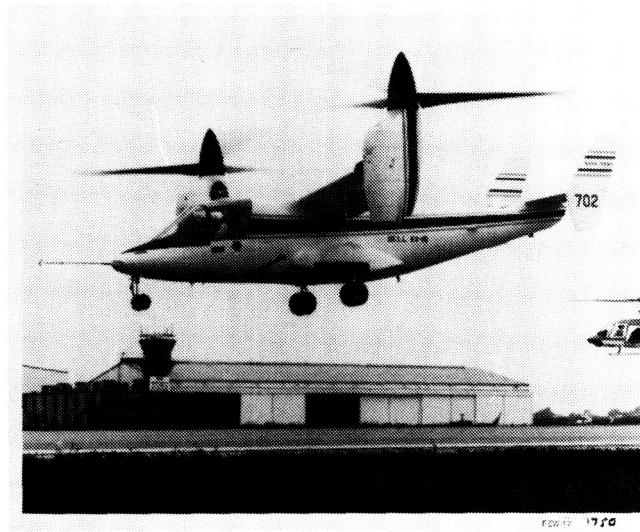


Figure 17.- First flight of XV-15 Tilt-Rotor Research Aircraft on May 3, 1977.

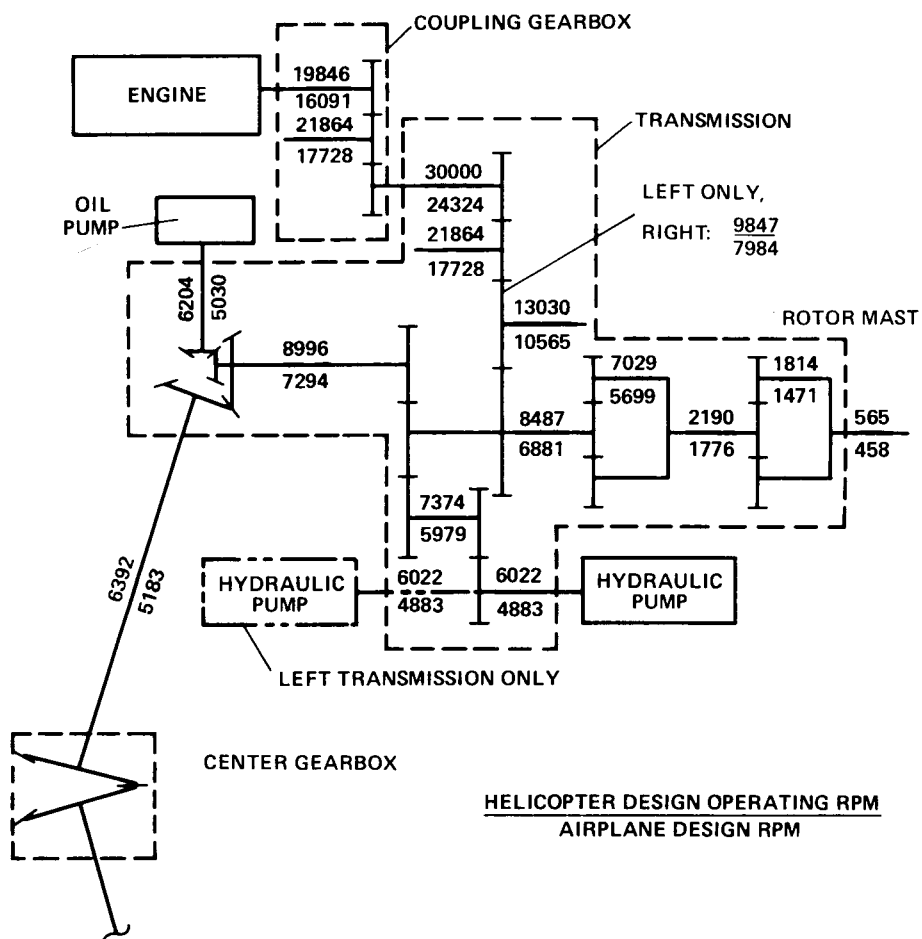
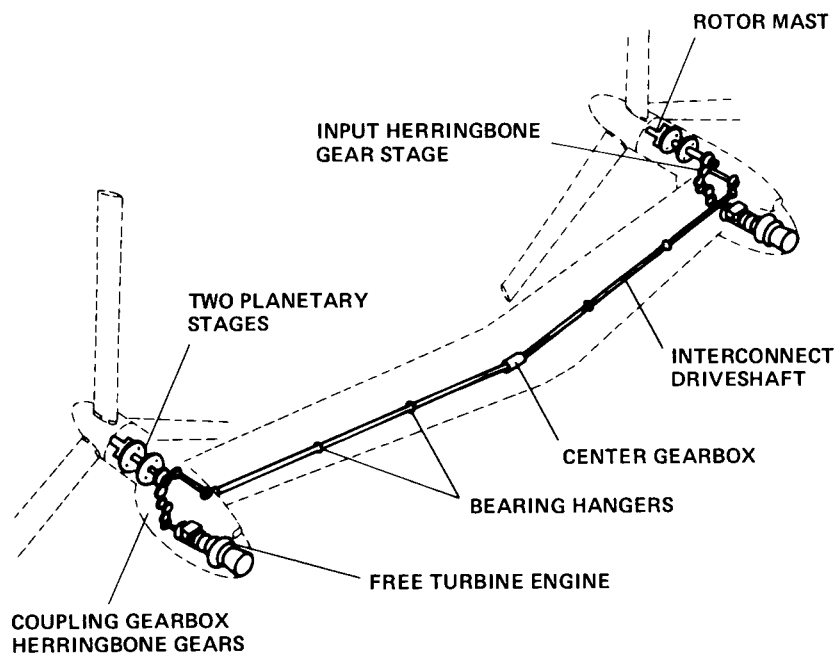


Figure 18.- XV-15 propulsion drive system, pictorial and schematic views.

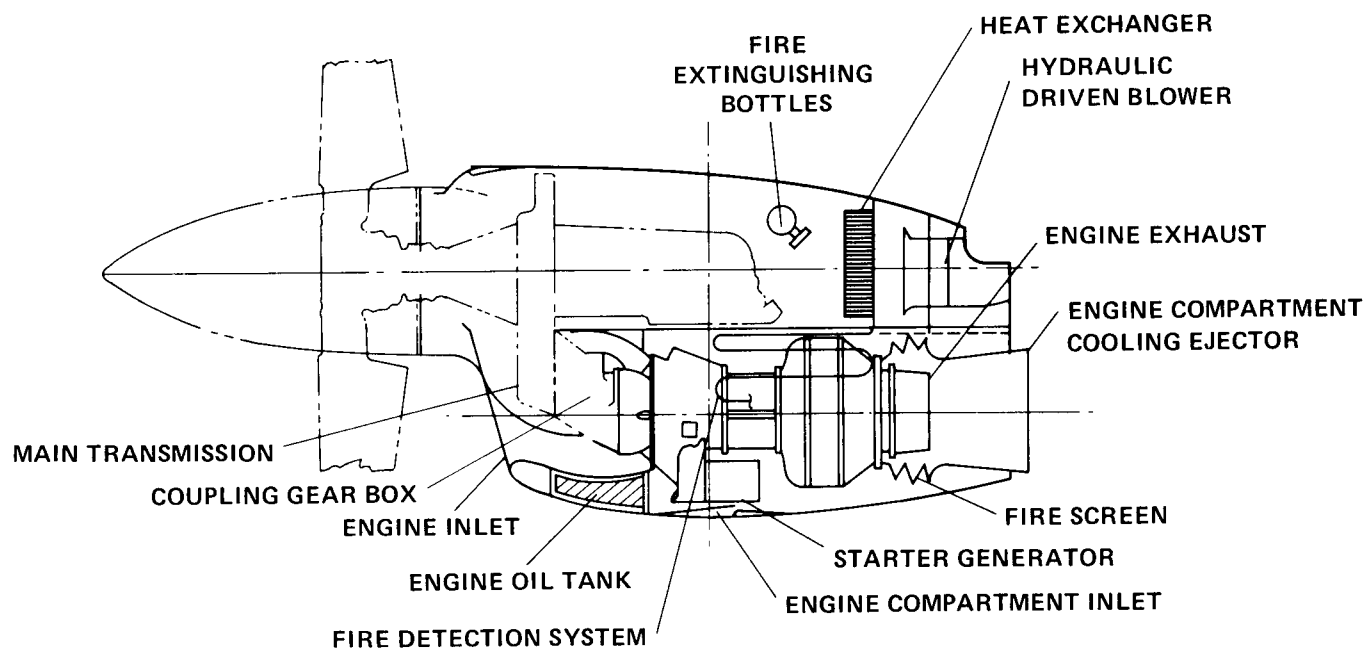


Figure 19.- XV-15 engine installation.

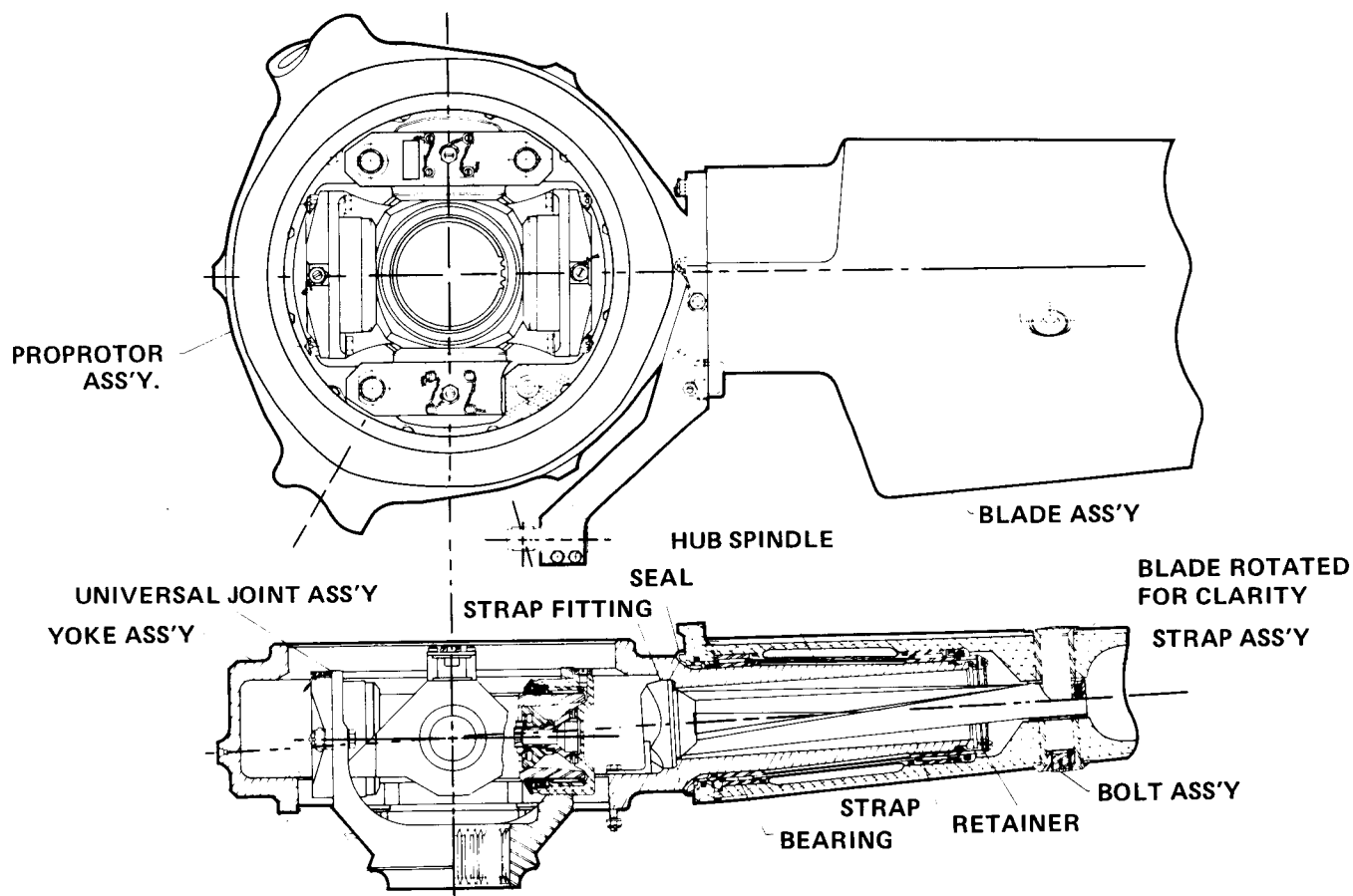


Figure 20.- XV-15 prop-rotor hub and blade-retention assemblies.



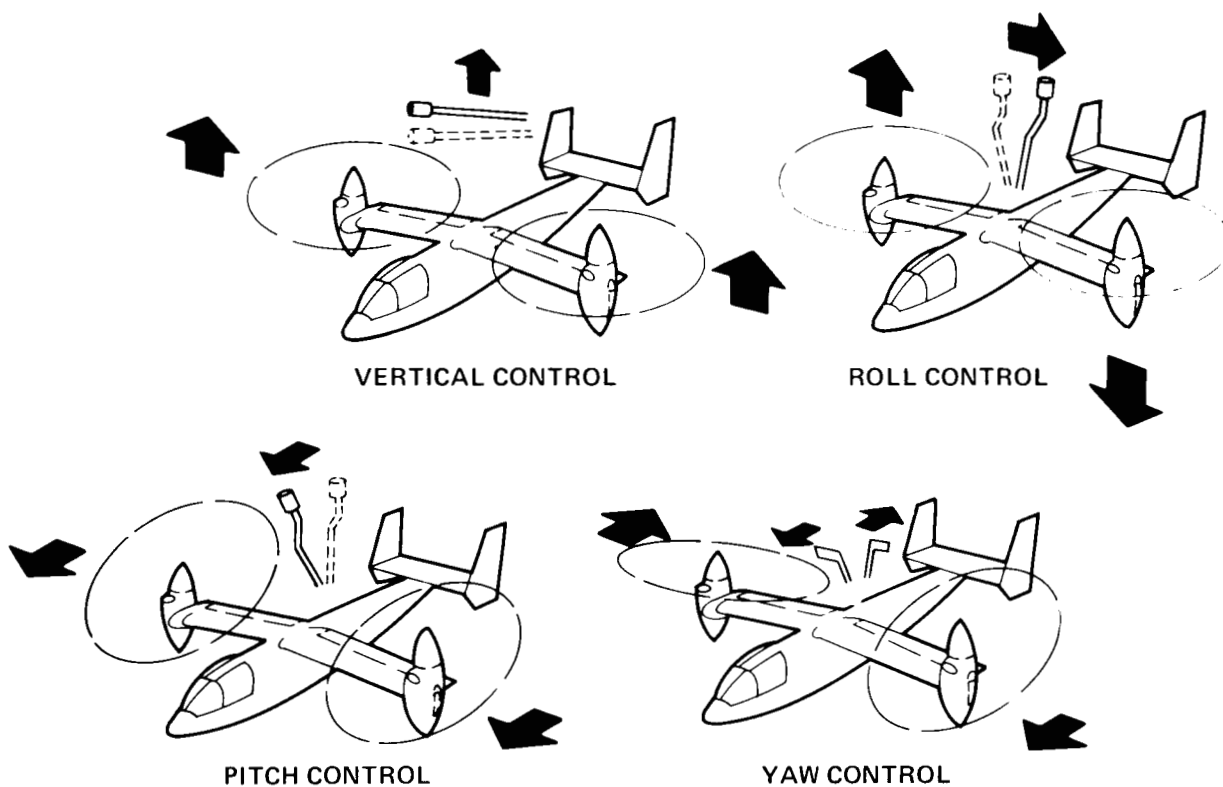


Figure 21.- XV-15 tilt-rotor control-system modes in helicopter flight.

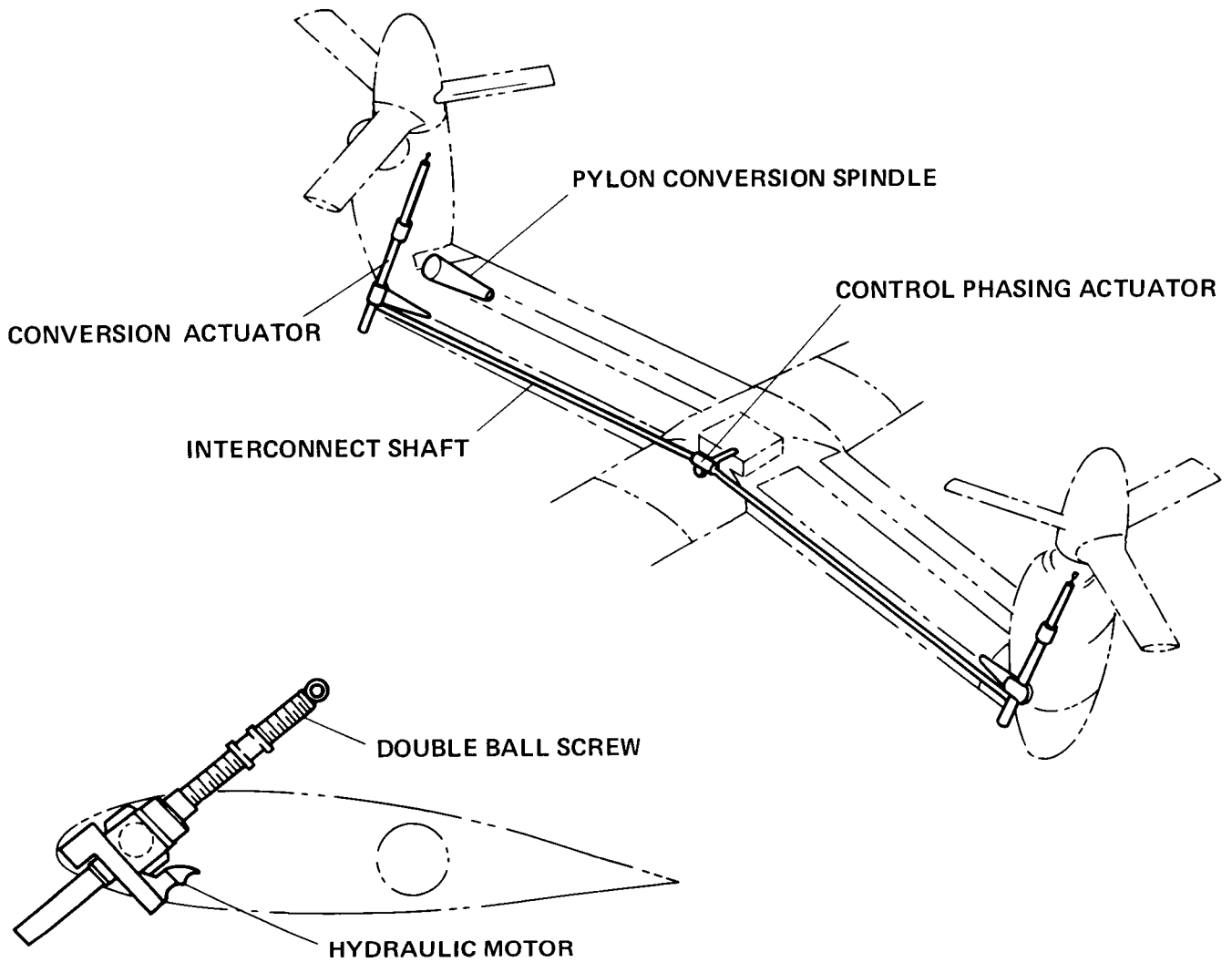


Figure 22.- XV-15 nacelle conversion system.

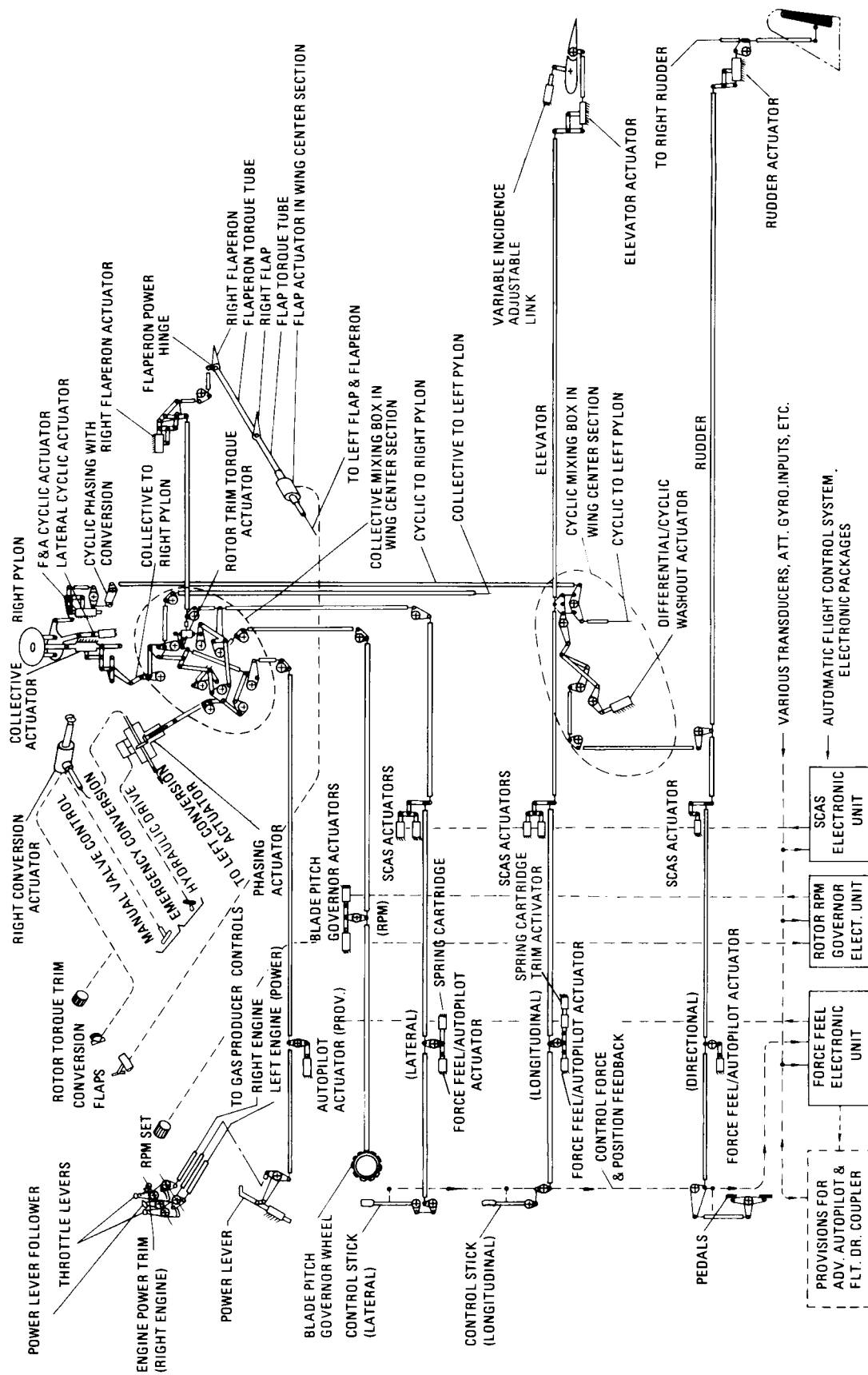


Figure 23.- Schematic of XV-15 mechanical flight-control system.

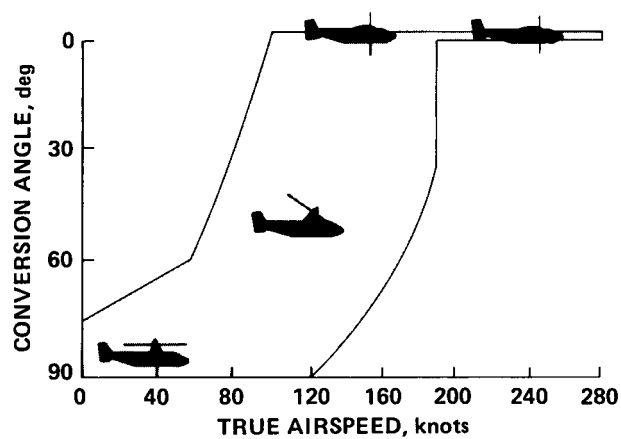


Figure 24.- XV-15 conversion envelope.

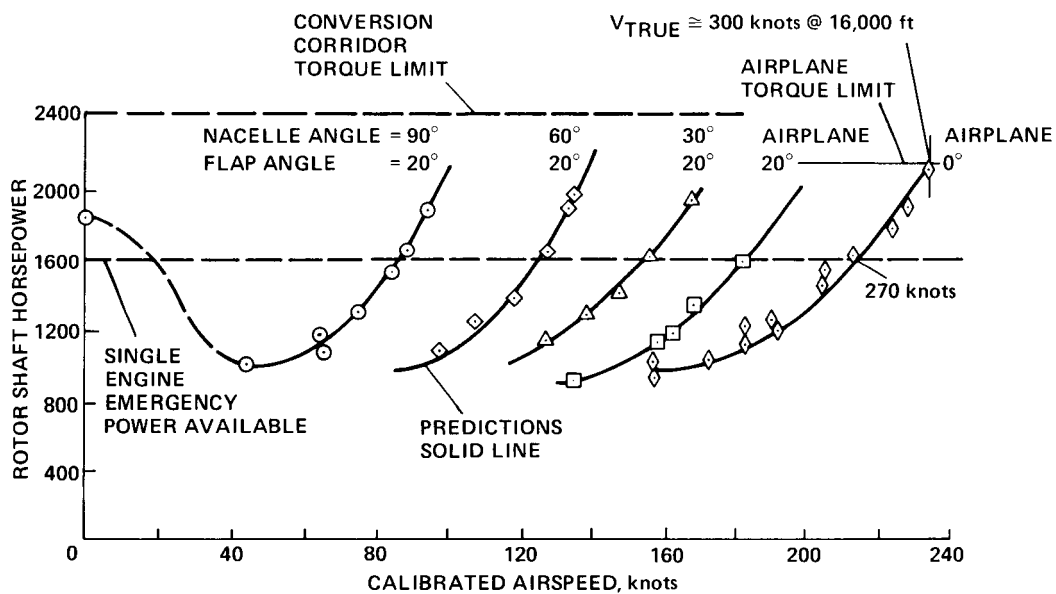


Figure 25.- Power required by XV-15 in various modes of flight.

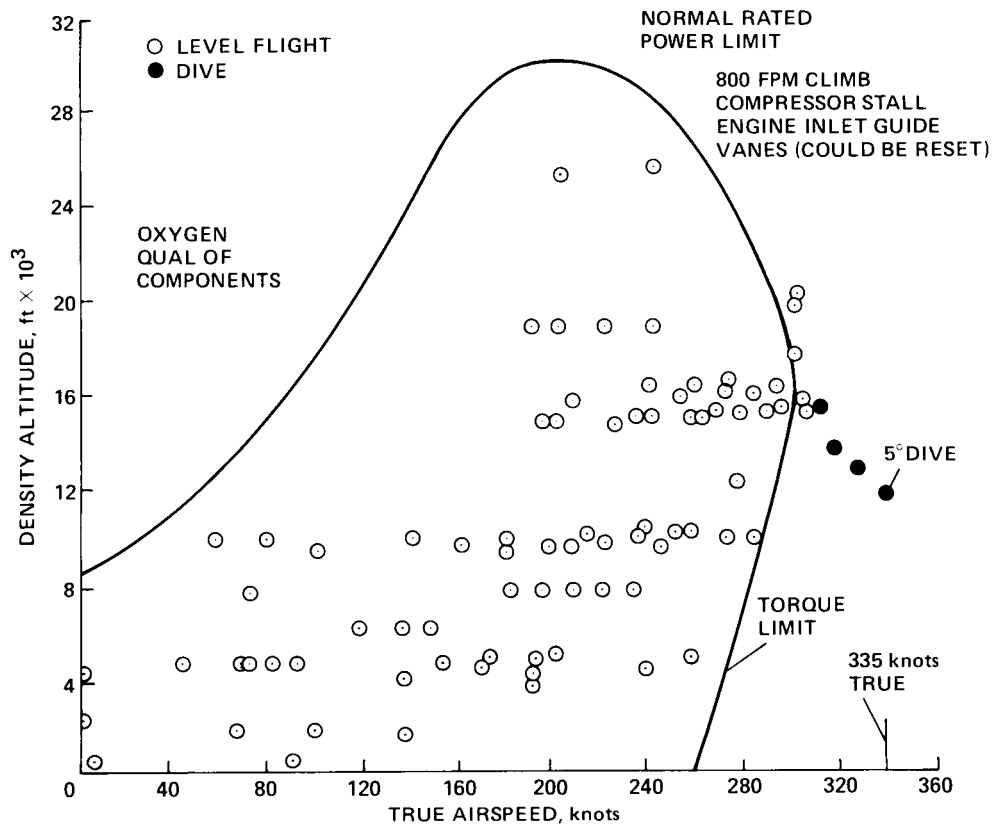


Figure 26.- XV-15 flight envelope.

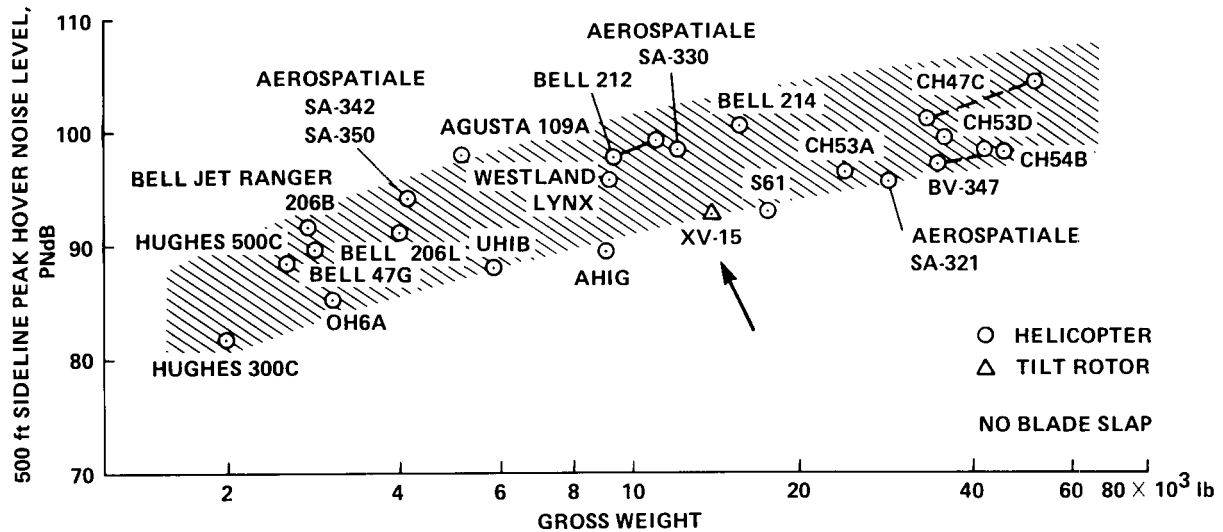


Figure 27.- Rotorcraft hover noise levels in PNdB vs gross weight.

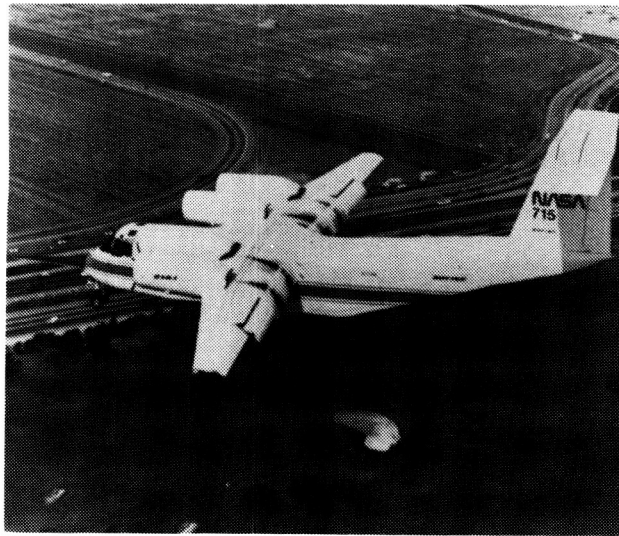


Figure 28.- QSRA on landing approach: USB flaps,  $50^\circ$ ; double-slotted flaps,  $59^\circ$ .

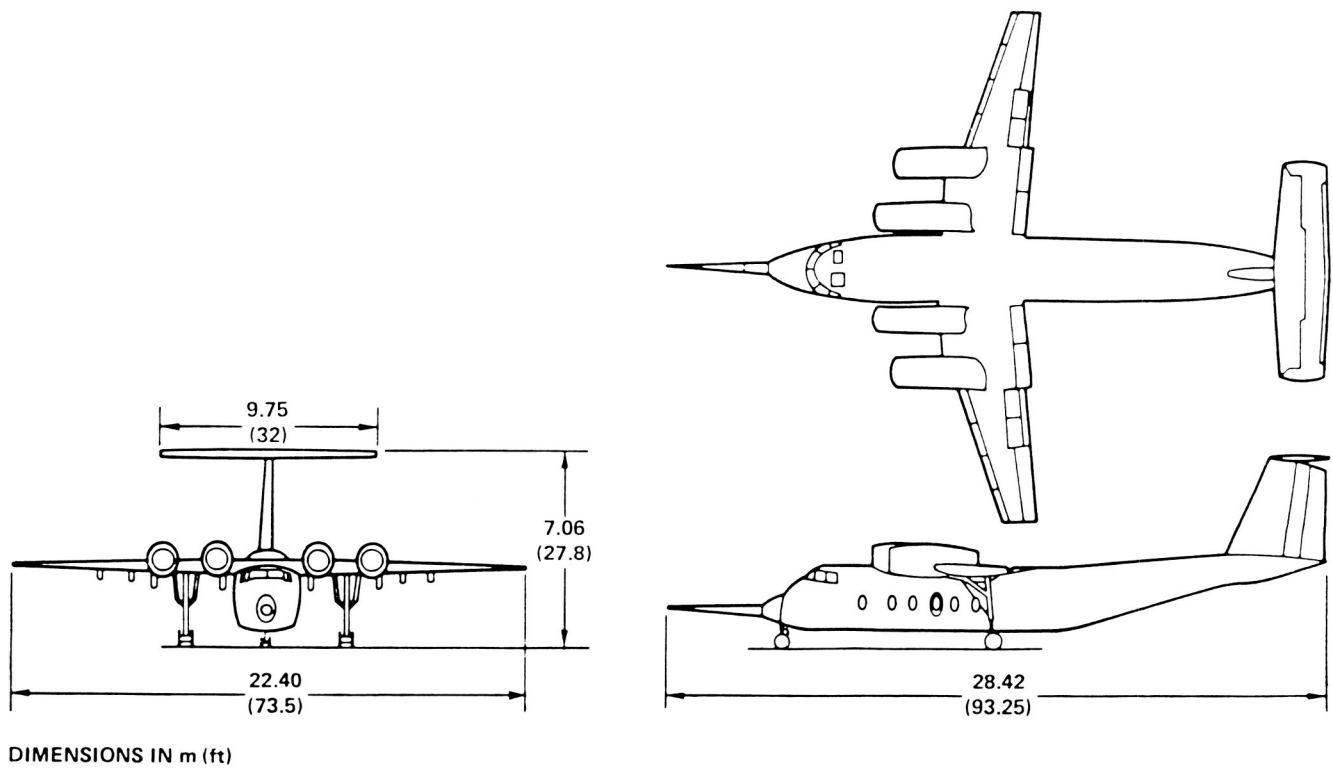


Figure 29.- Three-view diagram of QSRA.

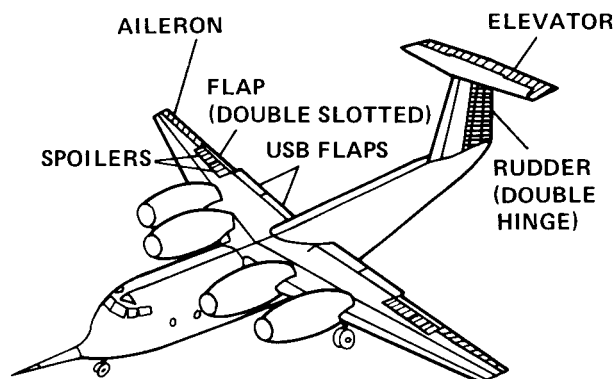


Figure 30.- QSRA flight-control surfaces.

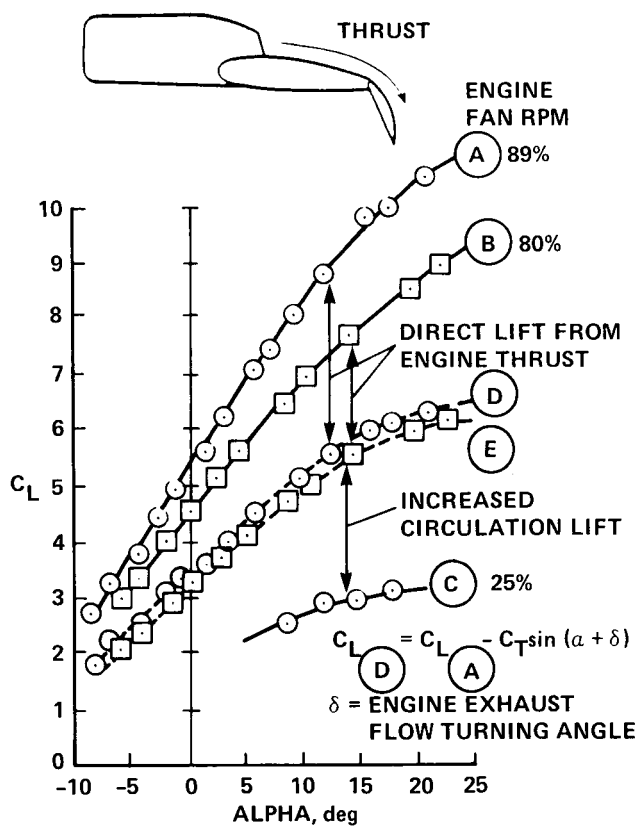


Figure 31.- QSRA lift vs angle-of-attack performance: USB flap, 50°; altitude, ~8,000 ft.

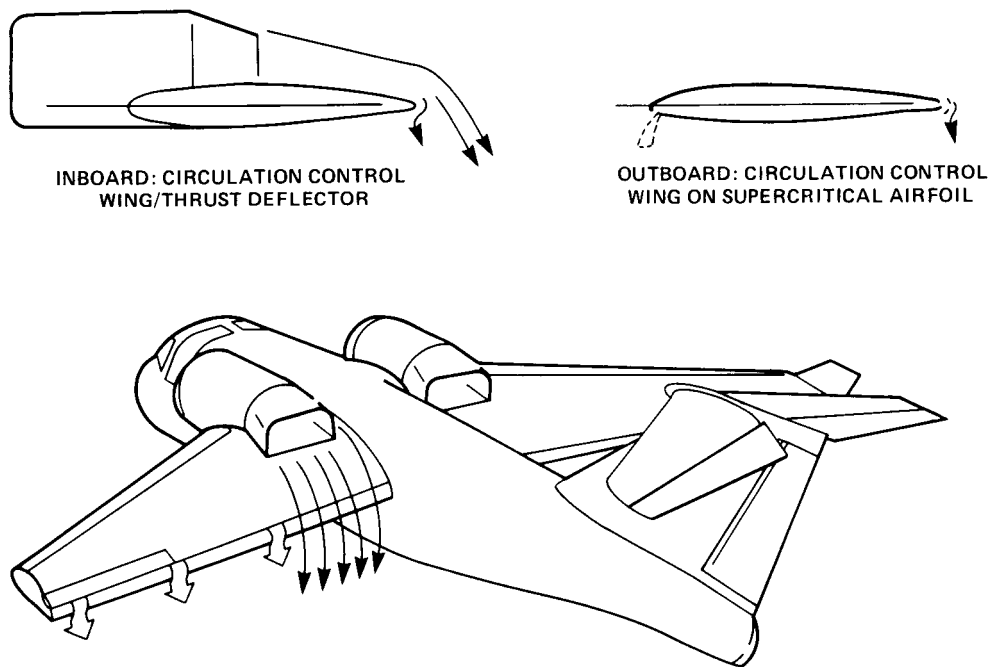


Figure 32.- QSRA in circulation-control wing/USB STOL aircraft configuration.

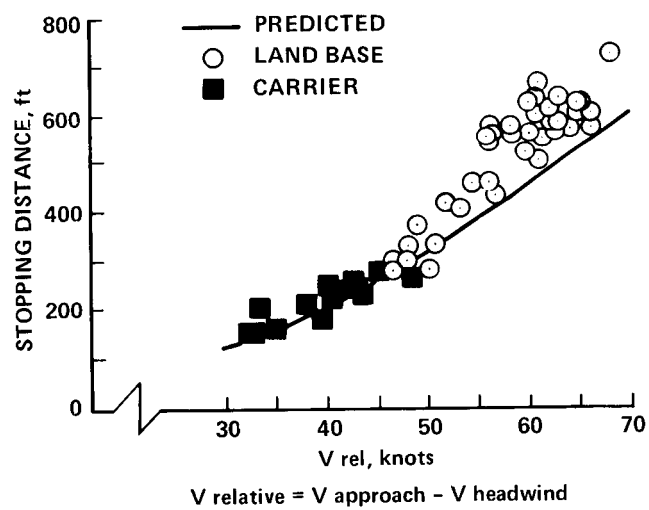


Figure 33.- QSRA stopping distance. Brakes only, land-based and carrier landings.



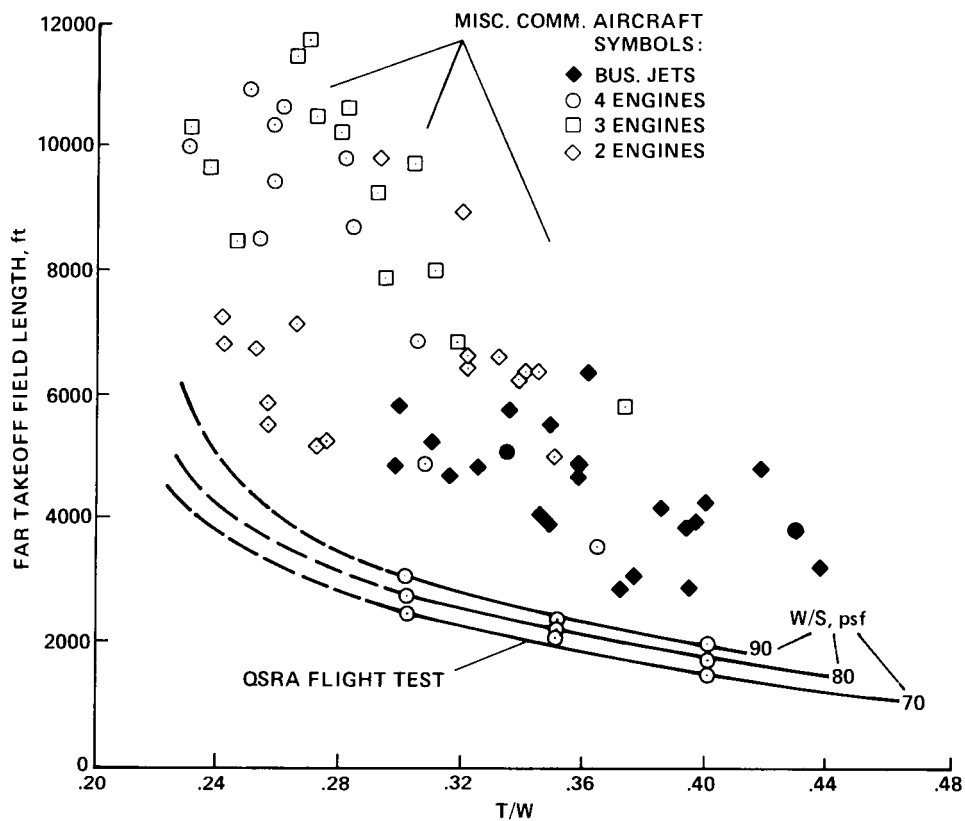


Figure 34.- Comparison of the Federal Aviation Regulation field lengths for various CTOL aircraft and QSRA; QSRA at several wing loadings (W/S).

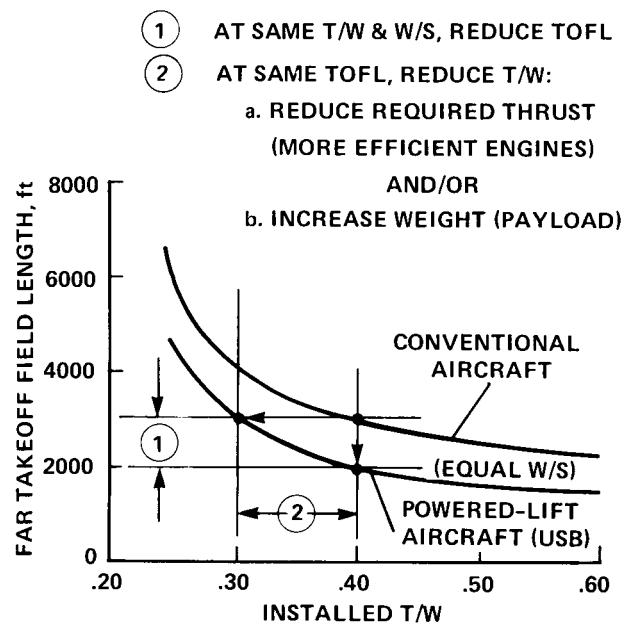
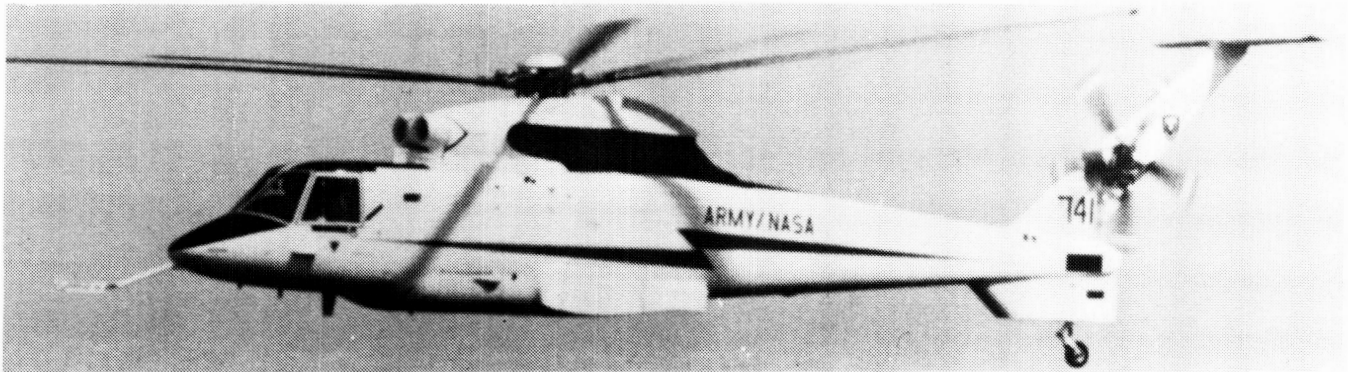
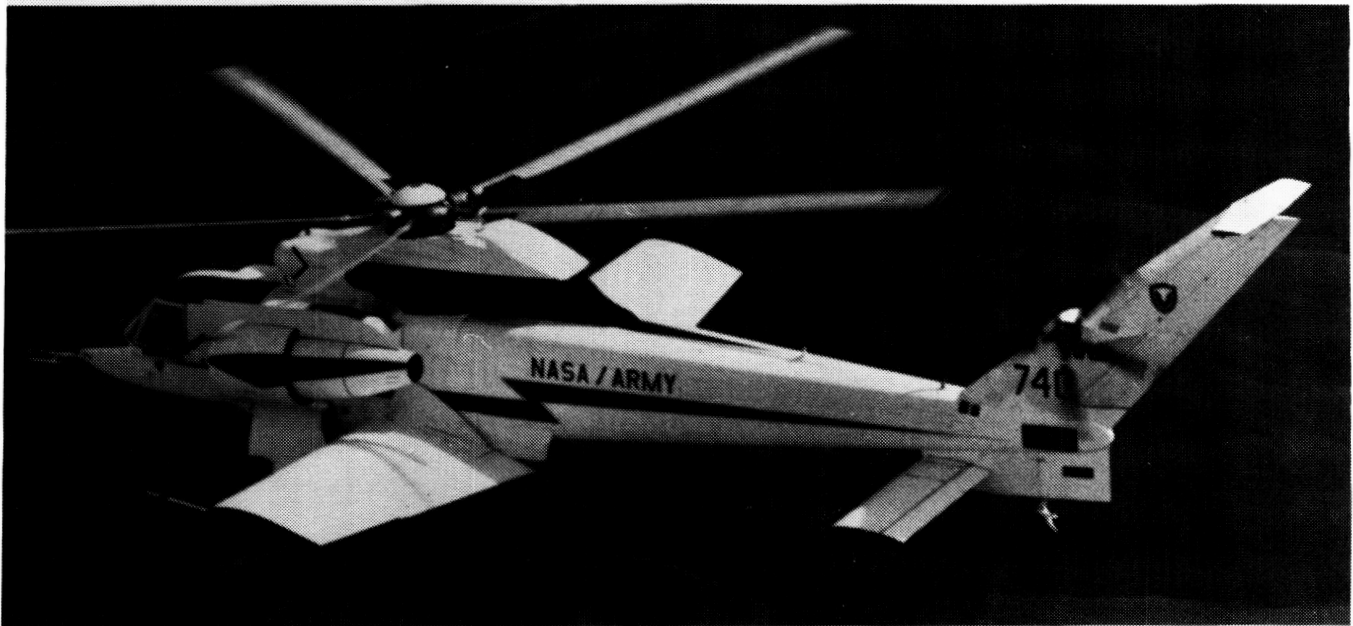


Figure 35.- Powered-lift USB potential benefits.

ORIGINAL PAGE IS  
OF POOR QUALITY



**HELICOPTER**



**COMPOUND HELICOPTER**



**FIXED WING**

Figure 36.- RSRA in its three flight modes.

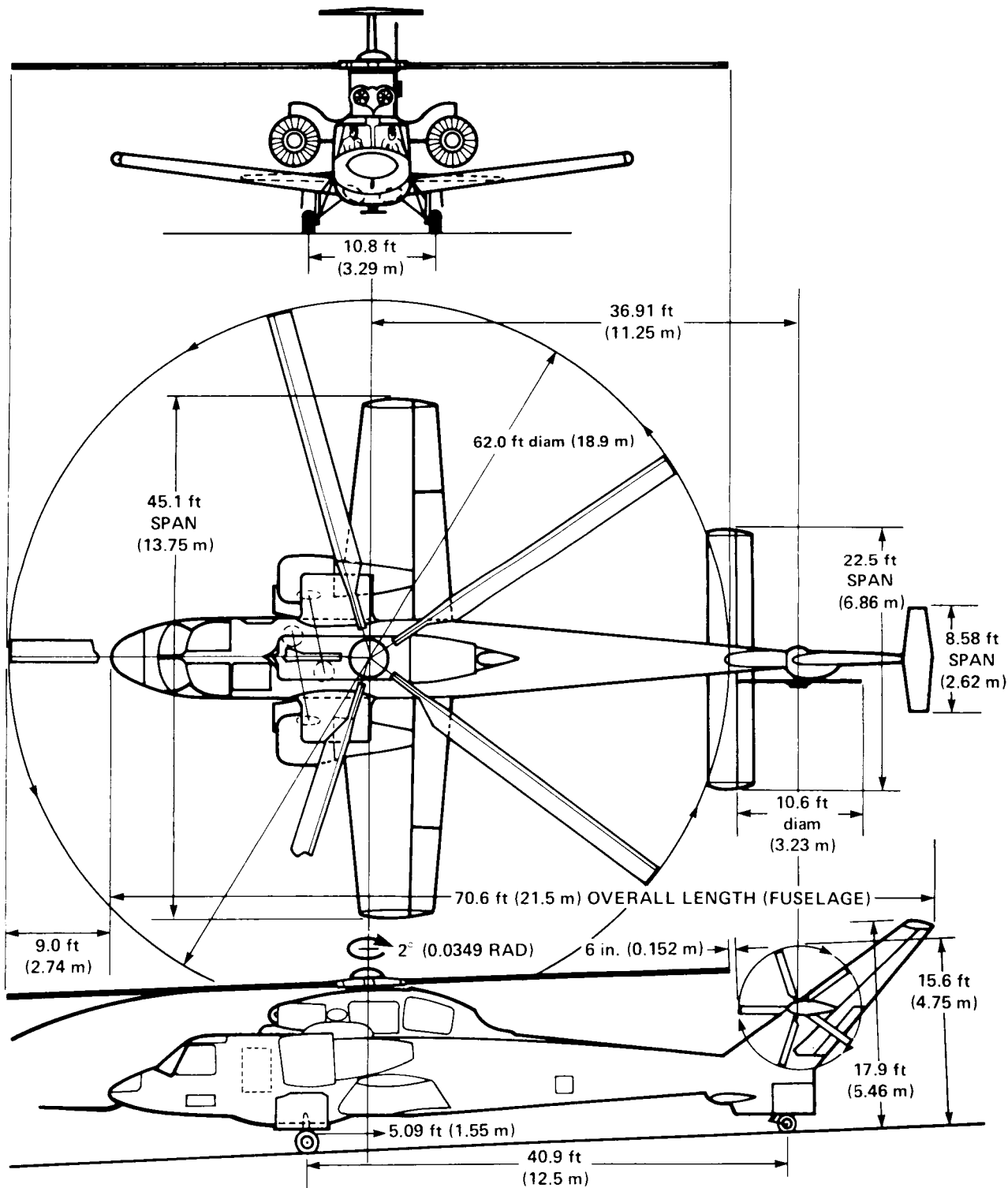


Figure 37.- Three-view diagram of RSRA-compound configuration.

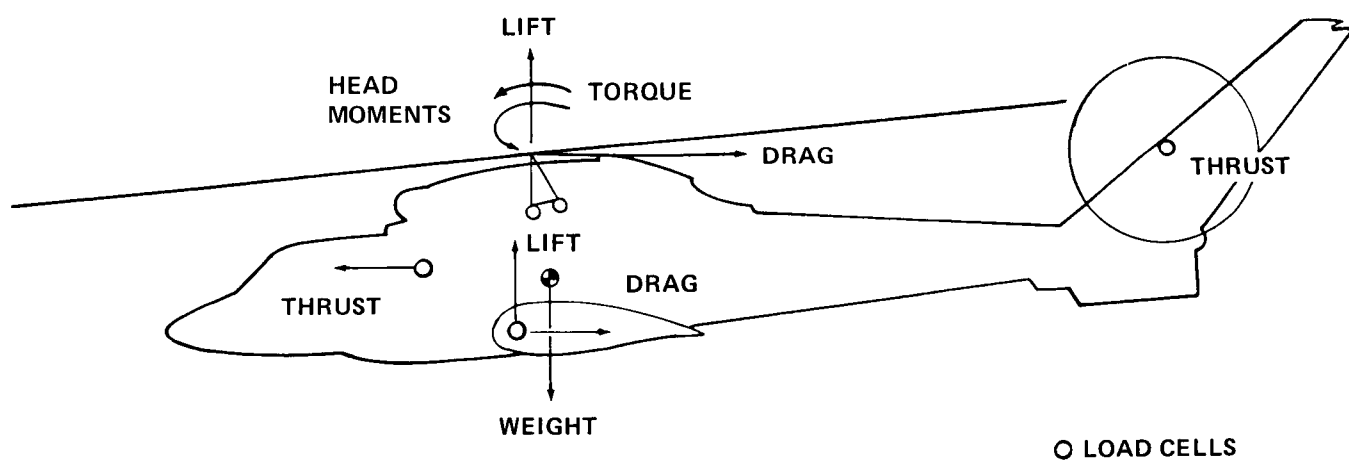
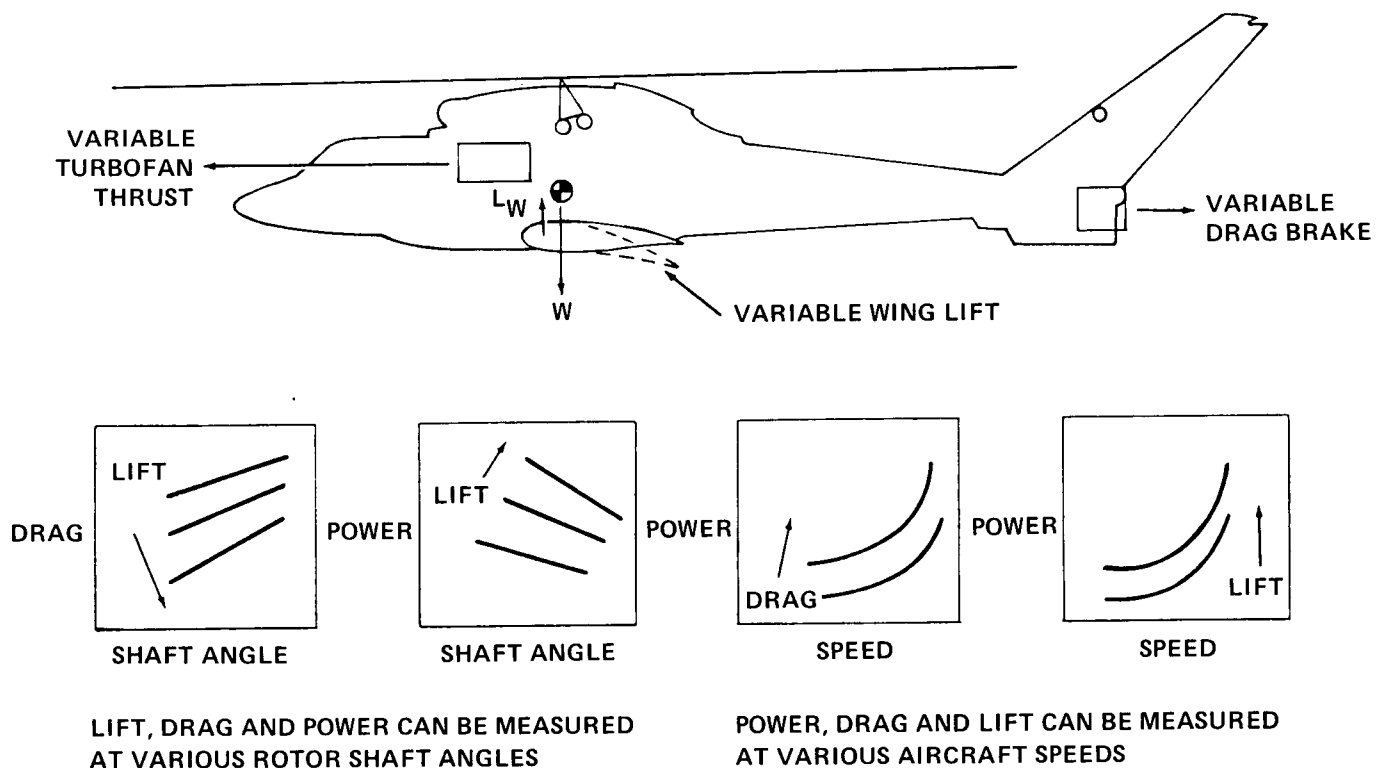


Figure 38.- RSRA force-measurement system.

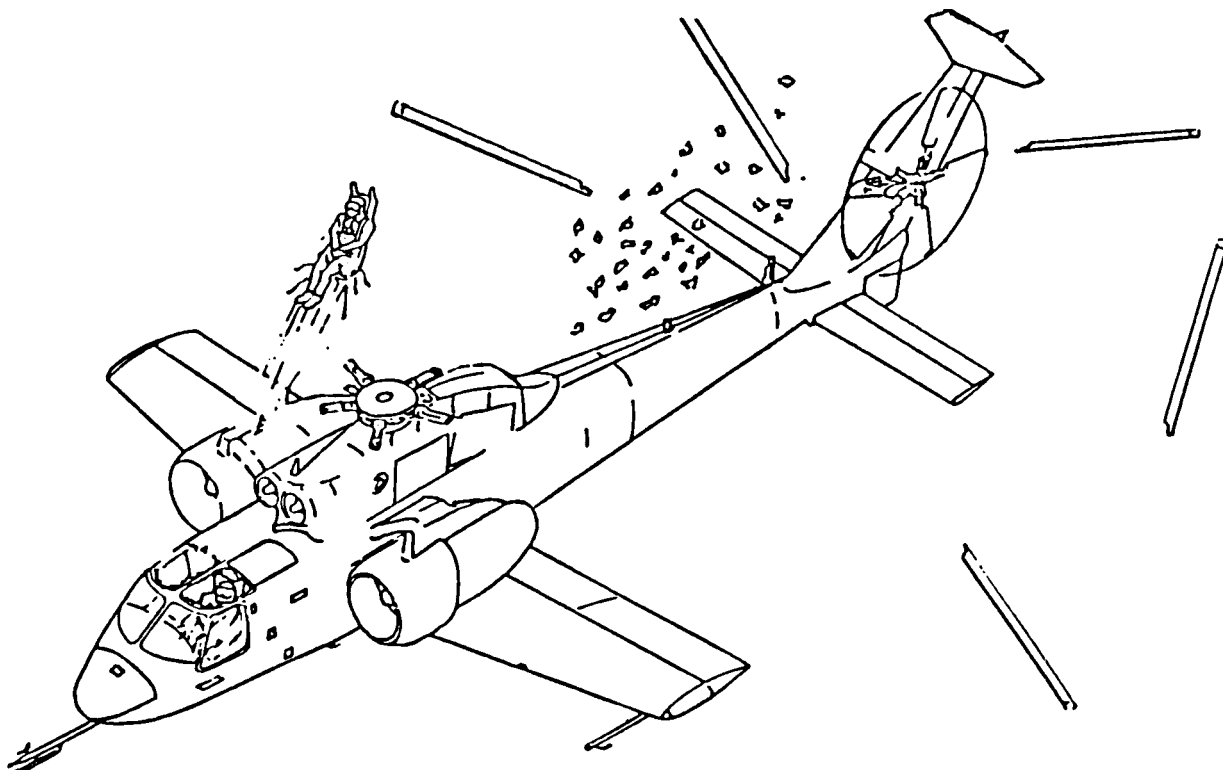


Figure 39.- RSRA emergency escape system operation.

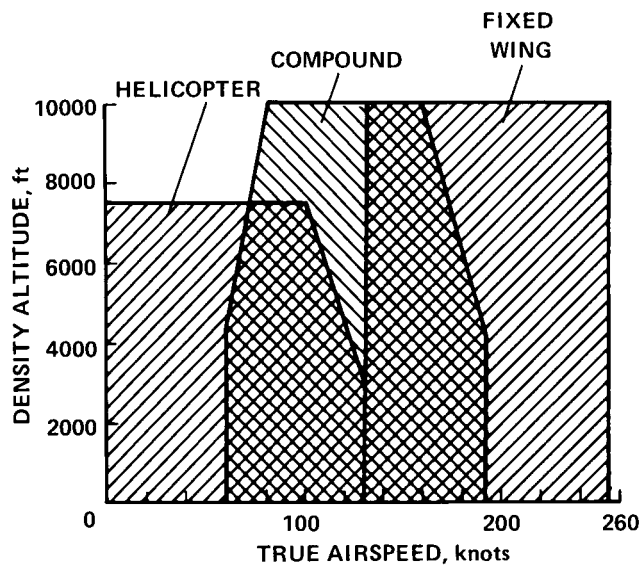


Figure 40.- RSRA demonstrated flight envelope.

ORIGINAL PAGE IS  
OF POOR QUALITY

## COMPOUND CONFIGURATIONS

- (1) { S.61 PERFORMANCE DOCUMENTATION  
      { ROTOR LIFT AND PROPULSIVE FORCE LIMITS
- (2) ROTOR STABILITY DERIVATIVES AND  
      VEHICLE PARAMETER IDENTIFICATION

## HELICOPTER CONFIGURATIONS

- (3) HOVER VERTICAL DOWNLOAD
- (4) LOW SPEED TRIM INVESTIGATION
- (5) VORTEX RING OPERATING CONDITION

Figure 41.- RSRA planned and approved flight experiments.



Figure 42.- RSRA/X-Wing in flight (artist's conception).

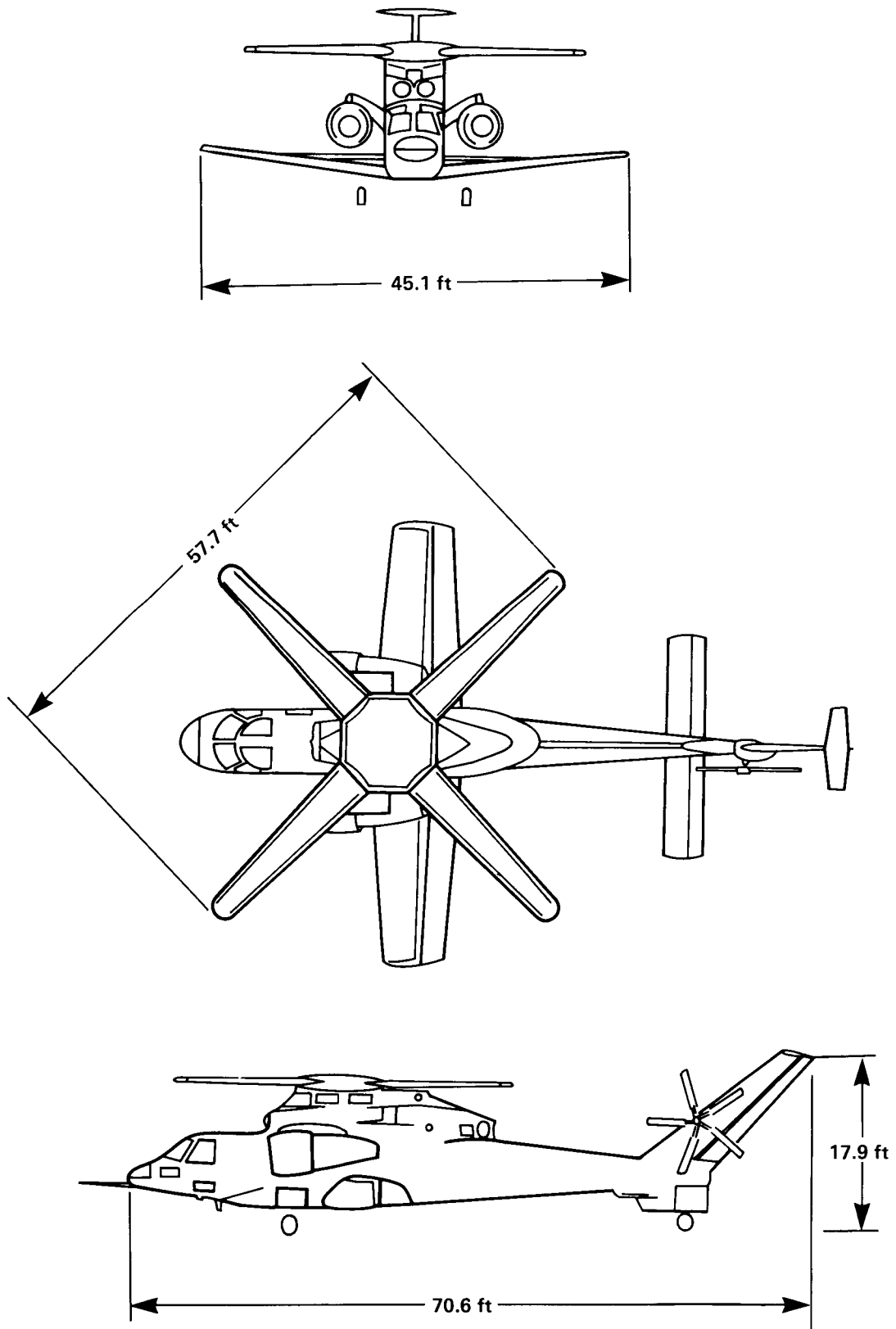


Figure 43.- Three-view diagram of RSRA/X-Wing.



Figure 44.- Operational X-Wing (artist's conception).

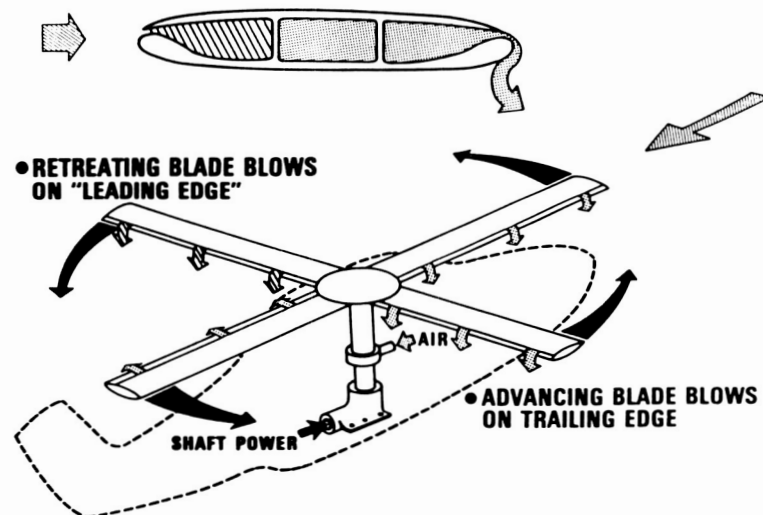


Figure 45.- X-Wing circulation-control rotor airfoil.



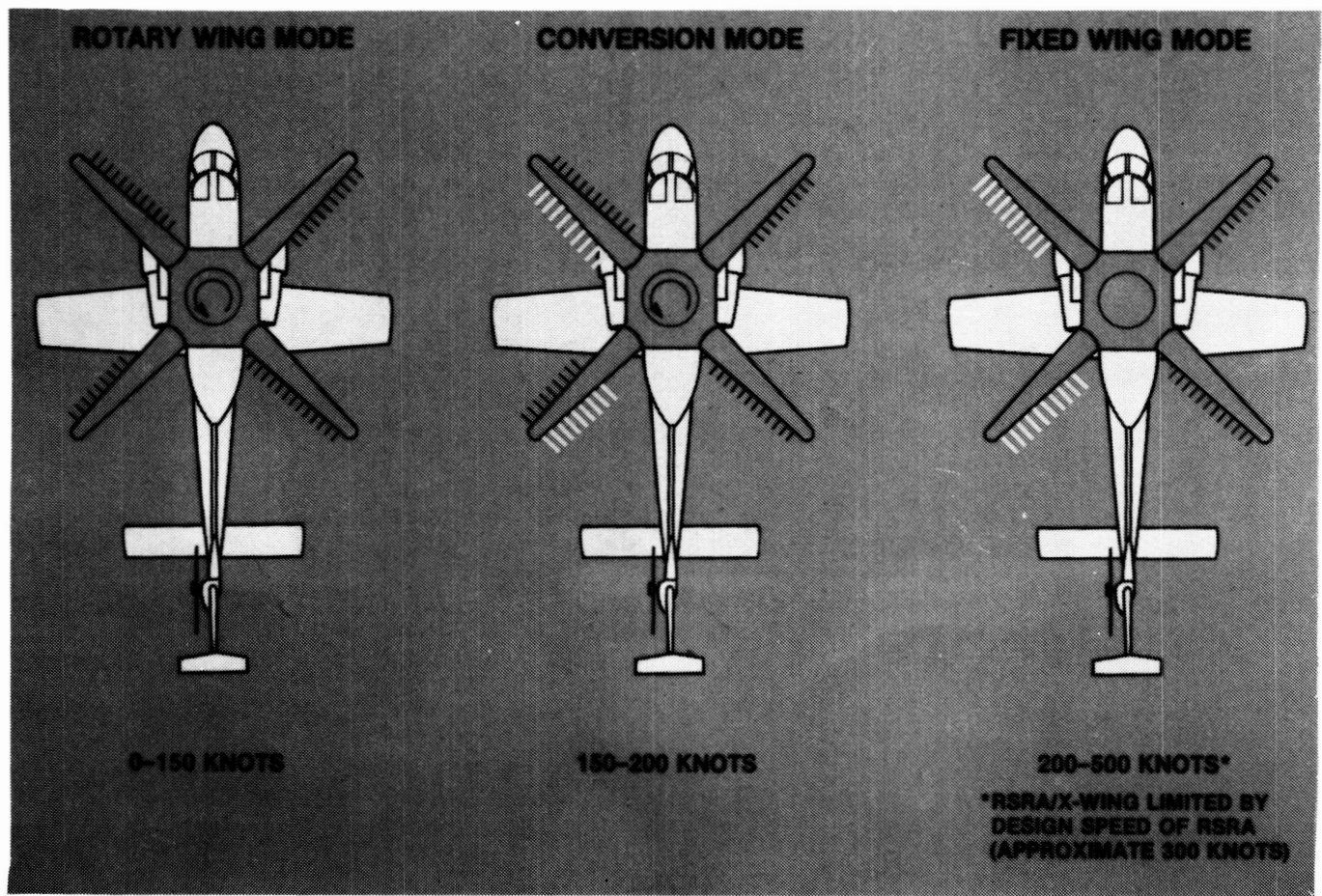


Figure 46.- X-Wing in its three flight modes.

ORIGINAL PAGE IS  
OF POOR QUALITY

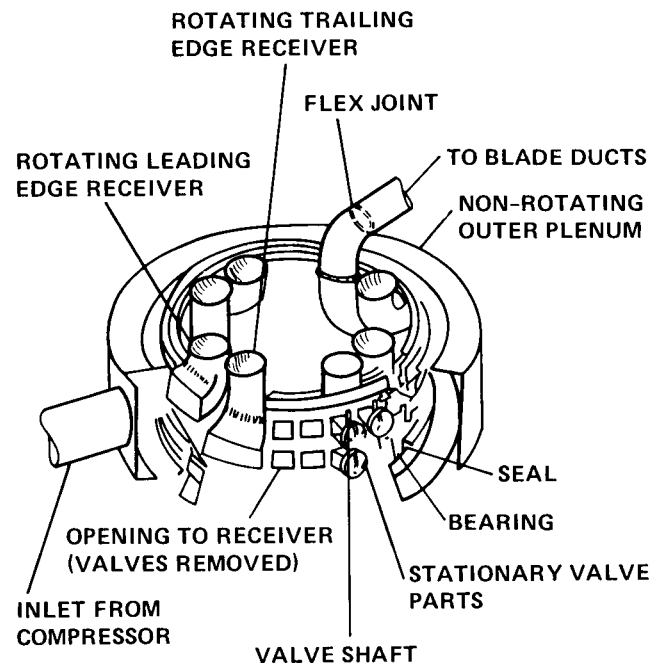


Figure 47.- X-Wing hub valving control.

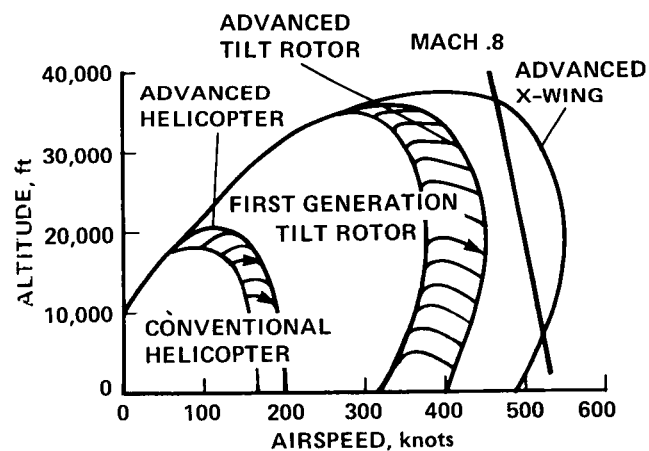


Figure 48.- Advanced X-Wing flight envelope compared to that of other rotorcraft.



## Report Documentation Page

1. Report No.  NASA RP-1187		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle A Perspective on 15 Years of Proof-of-Concept Aircraft Development and Flight Research at Ames-Moffett by the Rotorcraft and Powered-Lift Flight Projects Division, 1970-1985				5. Report Date August 1987	
				6. Performing Organization Code A-86404	
7. Author(s)  David D. Few				8. Performing Organization Report No.	
				10. Work Unit No. 505-61	
9. Performing Organization Name and Address  Ames Research Center Moffett Field, CA 94035				11. Contract or Grant No.	
				13. Type of Report and Period Covered Reference Publication	
12. Sponsoring Agency Name and Address  National Aeronautics and Space Administration Washington, D.C. 20546				14. Sponsoring Agency Code	
15. Supplementary Notes  Point of Contact: David D. Few, Ames Research Center, MS 237-2, Moffett Field, CA 94035, (415) 694-5445 or FTS 464-5445					
16. Abstract <p>This paper defines a proof-of-concept (POC) aircraft and briefly describes the concept of interest for each of the six aircraft developed by the Ames-Moffett Rotorcraft and Powered-Lift Flight Projects Division from 1970 through 1985; namely, the OV-10, the C-8A Augmentor Wing, the Quiet Short-Haul Research Aircraft (QSRA), the XV-15 Tilt Rotor Research Aircraft (TRRA), the Rotor Systems Research Aircraft (RSRA)-compound, and the yet-to-fly RSRA/X-Wing Aircraft. The program/project chronology and most noteworthy features of the concepts are reviewed. The paper discusses the significance of each concept and the project that demonstrated it; it briefly looks at what concepts are on the horizon as potential POC research aircraft and states the author's emphatic belief that it is safe to say that no significant advanced concept in aviation technology has ever been accepted by civilian or military users <u>without first completing</u> a demonstration through <u>flight testing</u>.</p>					
17. Key Words (Suggested by Author(s)) Powered lift Rotorcraft Experimental aircraft/flight research Proof-of-concept aircraft Experimental shop			18. Distribution Statement Unclassified - Unlimited  Subject Category - 05		
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified		21. No. of pages 54	22. Price A04	